MANUAL OF BIOLOGICAL FORMS

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MANUAL OF BIOLOGICAL FORMS

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PREFACE

In the present volume will be found descriptions of the structure and life processes of a number of representative animals and plants, together with directions for their study in the laboratory. This material has been prepared in the belief that "there is no adequate substitute for detailed laboratory work on the structure and physiology of representative organisms as a means of affording a first-hand knowledge of the facts and methods of biology" (Woodruff). It should not be inferred from this statement that the author feels that such a laboratory study constitutes the *primary* object of a course in General Biology. The latter certainly consists in giving the student a clear conception of the basic principles which govern living matter; but at the same time the student should acquire the scientific method of gathering related material from various sources and bringing it all to bear upon the problem at hand.

The question, then, is one of supplying the best method in order to accomplish the desired aim. The solution of the problem, in the course with which the author has been connected for a number of years, has come by so arranging the work that every possible emphasis is placed upon the fundamental biological principles by means of lectures, recitations, and demonstrations. In the laboratory, however, a careful search has revealed nothing that can take the place of thorough work on carefully selected representative types which, in their order of study, are taken up in a definite series proceeding from the relatively simple forms to the more complex.

For such a course, two types of texts are needed. In the first place, one which emphasizes the principles involved and

deals only incidentally with specific organisms, or, in other words, tells the story of biology in a connected fashion unobscured by too many details. Such is the *Foundations of Biology* by Professor L. L. Woodruff. In the second place, a text is needed which supplies a detailed description of the types studied in the laboratory, gives an adequate conception of their structure and life processes, and also links up the study of organism in such a way that, as the student progresses from day to day, he is able to get a vision of the whole field and to realize *why* a particular animal or plant is singled out for study. To accomplish this second need, the present volume has evolved along with, and as a complement to, Professor Woodruff's *Foundations of Biology*, to which page and figure references are given throughout.

In Part II are given the laboratory exercises which constitute the year's work at Yale. The development of these directions during the years that they have been used has been from the complex to the simple. They now represent, so to speak, the irreducible, morphological minimum to which can be added such physiological experiments, demonstrations, etc., as the personal equation of the individual teacher of biology dictates as necessary for the best development of his particular course.

The laboratory directions have been arranged so that, in general, each sheet embodies the work of a single laboratory period. It has been found desirable to have the laboratory work handed in each day for inspection. When the sheet is returned, it may be mounted in a loose-leaf note book together with the detached laboratory sheet, and thus at the end of the course each student will have a complete and permanent record of the laboratory work.

The material in this book has, of course, been obtained from many sources, but particular mention should be made of Hegner's College Zoölogy, Wilder's History of the Human Body, Holmes' Biology of the Frog, Martin's Human Body, Huxley's Lessons in Elementary Physiology (Revision by

Barcroft), Ganong's Textbook of Botany, Martin's Botany with Agricultural Applications, Marshall's Microbiology, Gager's Fundamentals of Botany, and Kingsley's Vertebrate Zoölogy.

At various stages in its development, the manuscript and book as used in a temporary form have been read by my colleagues at Yale, Professors Harrison, Coe, Woodruff, Petrunkevitch, Laurens, Swingle, Buchanan, and Dr. Hill to all of whom the author feels greatly indebted. Special credit is due to Professor Woodruff, at whose suggestion the writing of the book was undertaken, and whose critical reading of the material at every stage in its development has been of the utmost value. The author also desires to acknowledge his great obligation to his wife, Dorothy Morton Baitsell, and to Miss Vivian Dyson Alling of the Yale Laboratory for the editorial work they have done, particularly on the index. Finally, the author desires to express his appreciation to the MacMillan Company for the great consideration they have shown in all arrangements connected with the publishing of this volume.

George A. Baitsell.

Yale University,
July, 1923.

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PART I

DESCRIPTIVE

MANUAL OF BIOLOGICAL FORMS

I. THE ORGANIZATION OF LIVING MATTER

The world in which we live contains a great many forms of living organisms which are known to us either as plants or as animals. The study of all living matter, whether obtained from a plant or from an animal, constitutes the subject matter of Biology as distinguished from Botany, which deals entirely with plants, and from Zoölogy, which deals entirely with animals (W. pp. 1–5).[1]

Living matter is technically designated as protoplasm, and wherever found, exhibits certain characteristics, such as a peculiar chemical composition, the power of metabolism, the power of growth, the ability to reproduce, the power of adaptation, and, finally, a definite organization. These characteristics collectively serve to differentiate it from lifeless matter (W. pp. 6–20).

Among the characteristics just given, the one with which we are particularly concerned at present is that of organization. Protoplasm always occurs in the form of microscopic living units, termed CELLS. In other words, the protoplasm present in a plant or an animal is not a single, unorganized mass, but is divided into definite bodies, the cells. In the lowest forms of life, the entire organism consists of a single microscopic cell which is able to perform the essential life processes. In the higher forms of life, the organism is built up of an almost inconceivable number

[1] The references in this book designated by W. refer either to pages or to figures in Woodruff's Foundations of Biology, 2d edition, 1923. (Macmillan.)

of cells, groups of which are specialized for certain definite duties in the life of the individual, such as nutrition, reproduction, sensation, etc. Inasmuch, therefore, as the cells are the fundamental units of all living organisms, the study of them is the logical starting point for the attainment of biological knowledge (W. pp. 21–29).

A. The Structure of Cells

One of the easiest ways to get an idea of the cellular organization of living things is to make a microscopic examination of a bit of the outer epidermis stripped from the surface of a green leaf. This material forms a thin layer which encloses the leaf and, in fact, all parts of a plant. It will be at once apparent, as the result of such an examination, that the epidermis of the leaf is not composed of a sheet of homogeneous material, but, on the contrary, consists of a great number of tiny but definite units — the cells. The latter are in close contact on all sides, thus forming a tissue. The examination of the various parts of any multicellular plant or animal shows that a condition essentially similar to that just described is of universal occurrence (W. fs. 4–6).

It is also important that a clear conception be obtained of the fact that a cell is not a flat surface, as it appears when a section of some tissue is studied under the microscope, but that it is a solid, having length, breadth, and thickness. The various dimensions of the cells, which compose a plant or animal tissue, can be obtained by a microscopic study of material which has been sectioned in different planes. We may take as an example sections through the root-tip of an Onion. In general, the cells present are so arranged that a longitudinal section shows them from what may be termed a side view, thus giving the length and the breadth. A transverse section, on the other hand, shows an end view of the cells from which the thickness as well as the breadth may be noted. From these two views, therefore, the three dimensions of the cells may be obtained. The same principle

can be applied in the study of various other plant or animal tissues. A study of the red corpuscles, great quantities of which are present in blood, shows these cells as solids (W. f. 7, J). A rough comparison is often made between the cells which make up a living organism, and the bricks which make up a house. Such a comparison may, perhaps, give one a faint conception of the architecture of a living organism, but it fails to indicate the amazing potentialities of these fundamental protoplasmic units of all organisms.

The different types of cells, although showing considerable variation, nevertheless exhibit a fundamental similarity in structure (W. f. 7). There is typically an outer limiting membrane, or CELL WALL, which is often regarded as an accessory, non-living part of a cell. It is probably formed — at least in many cases — as a secretion by the outer layer of living matter. Its chemical character usually differs markedly in plants and animals. In plant cells the comparatively thick cell wall is composed of a substance, known as cellulose, which is similar to starch in its chemical composition, while in animal cells the wall is protein in character. Whatever its chemical nature the cell wall is permeable to certain liquids and gases, and thus it is that the cells receive and discharge all of the materials necessary for their continued existence (W. f. 8; p. 445, Osmosis).

The cell wall encloses the essential protoplasm which is differentiated into CYTOPLASM and a very small central body, the NUCLEUS (W. f. 8, *a–d*). In the cell cytoplasm, as a rule, an outer layer (ECTOPLASM), which lies next to the cell wall, is of a somewhat different nature than the more abundant inner portion (ENDOPLASM) in which the nucleus lies. This differentiation between ectoplasm and endoplasm is particularly marked in the unicellular animals. Various other inclusions in the cytoplasm are to be found. For example, in plant cells, the cytoplasm usually contains a number of pigment-bearing bodies, the PLASTIDS (W. f. 8, *g*). Some of these plastids (CHLOROPLASTIDS) contain the es-

sential food-forming substance of green plants (CHLOROPHYLL) which will be considered in detail later. Not all of the cytoplasmic inclusions in a cell consist of living matter, and various non-living substances, collectively termed METAPLASM, are present (W. f. 8, *e*). The metaplasm in a cell varies in amount and character at different times and comprises both waste products and reserve food materials. These substances may be in the form of water vacuoles, fat droplets, crystals, etc. Typical mature plant cells frequently contain a large central cavity, or CELL VACUOLE, filled with a fluid, termed the CELL SAP, which contains materials of importance in the life of the cell (W. f. 8, *f*). The cytoplasm also contains a small spherical body, lying near the nucleus, in which is the CENTROSOME. The latter plays an active part in cell division (W. f. 8, *h*).

Surrounding the nucleus in a resting cell, that is, one which is not undergoing division, is a definite NUCLEAR MEMBRANE. The protoplasm, which constitutes the nucleus, is known as KARYOPLASM. A delicate network is frequently present, composed of LININ fibers (W. f. 8, *c*). The nucleus also contains an extremely important material which stains very deeply with certain dyes and is, therefore, known as CHROMATIN (W. f. 8, *b*). There is a great abundance of evidence at the present time which goes to show that the chromatin in the nucleus of a cell is the vehicle for the transmission of hereditary characters, and therein lies its great importance. Frequently a tiny spherical body, the NUCLEOLUS, is present in the nucleus. Its function is more or less obscure (W. f. 8, *a*).

B. THE LIFE PROCESSES OF CELLS

1. *Metabolism*

In all living cells, certain metabolic processes are continually taking place which involve an interchange of materials between a cell and its environment. The income

consists of food materials in solution and oxygen, and the outgo consists of waste materials in solution and carbon dioxide. All of these substances are exchanged through the cell wall. The movement of materials through the cell wall is believed to be governed by the underlying cytoplasm. It is probable that the katabolic processes of the cell are largely centered in the cytoplasm, while the anabolic processes of repair and growth, together with the control of cell division, are largely centered in the nucleus. The nucleus is generally regarded as the governing and directive agent for all the activities of the cell.

The processes involved in metabolism are essentially the same in both plant and animal cells. However, in addition to the fundamental metabolic processes which are present in all cells, in cells containing chlorophyll another important process takes place, known as PHOTOSYNTHESIS, by which the green plants are able to build up their food from the simple inorganic elements of their environment. This important process is superimposed, as it were, upon the underlying, fundamental metabolic processes.

2. *Cell Division*

One of the most extraordinary characteristics of protoplasm is the ability to reproduce itself, and this process always takes place as a result of cell division. Cells multiply by MITOTIC CELL DIVISION. This is a very complicated process and involves profound nuclear changes which result in the correct qualitative and quantitative division of the chromatin material in the nucleus of the cell. Since the chromatin material is the vehicle for the transmission of hereditary characters, the necessity for an accurate division of this material is evident (W. pp. 224–228).

3. *Movement*

The power of movement, although almost always associated with protoplasm, is not confined exclusively to it.

This fact can be demonstrated by adding to water a small amount of an insoluble, finely ground powder. A microscopic examination of a drop of the mixture reveals a continual irregular oscillatory movement of the insoluble particles in the water. This noteworthy phenomenon is known as BROWNIAN MOVEMENT, and it can be explained upon a purely physical basis.

Although movement is not confined exclusively to living organisms, it is nevertheless one of the very striking features of both plant and animal protoplasm. In many of the unicellular plants, or Protophyta, such as Sphaerella, a definite locomotor apparatus is present at certain stages in the life history. This apparatus consists of a number of fine filaments, the FLAGELLA, which vibrate vigorously, and thereby the individual is propelled through the water at a comparatively rapid rate (W. f. 9).

In the higher multicellular plants, which are attached and, therefore, cannot move from place to place, a slow but definite movement of certain parts may take place. It is, for example, a matter of common observation and knowledge that the leaves of house plants adjust themselves in relation to the source of light, and that the flowers of certain green plants, like the Sunflower, keep slowly turning during the day so as to receive the full benefit of the sun's rays. Furthermore, there are plants which are able to move various parts with considerable rapidity in response to environmental stimuli of various kinds. A good example of this is to be seen in the Sensitive Plant (*Mimosa pudica*) which is a member of the Pea family. If the leaves of this remarkable plant are touched or disturbed in any other way, there is an almost immediate response which results in a drooping of the leaf stalk and a closing up of the blade of the leaf. Shortly after the disturbance has passed the leaves return to their original position.

Again, a microscopic examination of the living tissues of plants reveals, in many instances, a striking intracellular

protoplasmic movement; that is to say, a movement of the protoplasm within each cell. This type of movement is often referred to as a protoplasmic streaming. It may be seen to advantage in the common fresh-water plant, *Elodea canadensis*. The young active leaves of this plant can be obtained from near the tip of the stem and mounted in a drop of water for microscopic examination. The cells of the leaf are, in general, rectangular in shape and possess a quite heavy cell wall, within which is a layer of transparent cytoplasm. Embedded in the latter are a number of green, disc-shaped chloroplastids, and also the nucleus. A large cell vacuole filled with cell sap is present and occupies the center of the cell. A close microscopic examination of the chloroplastids in a number of the cells will generally show that they are in motion, travelling around and around just inside the cell wall. This motion is due to the streaming of the cytoplasm in which the chloroplastids are suspended, that is, they are merely carried along in the protoplasmic current. Protoplasmic movement similar to this may be observed in the cells of many other plants. It is also strikingly shown in certain animal cells, as, for example, in various of the Protozoa. Thus, in Paramecium the food particles are moved in a definite path in the cell by a streaming, or CYCLOSIS, of the cytoplasm (p. 29).

In animals various types of movements are found. In the unicellular animals an irregular flowing, or AMOEBOID, movement can be observed in the Amoeba and various related forms. In such animals a definite cell wall is lacking, and the cytoplasm is free to flow in such directions as the environment will permit. Temporary irregular projections, or PSEUDOPODIA, are thus being continually formed and withdrawn. In the large group of flagellated Protozoa, one or more flagella are present, which, as in Sphaerella and other Protophyta, aid in locomotion. In some of the Flagellates, for example, Euglena (p. 22), the cell wall is very thin, and the movements of the cytoplasm result in a peculiar

squirming, or EUGLENOID, type of movement, but the irregular pseudopodia are not formed. Finally, a large class of the Protozoa, the Infusoria (p. 26), are ciliated. In such cases great numbers of extremely fine filaments, the cilia, are formed as projections from the ectoplasm. These may be of uniform size and distribution over the animal, as in Paramecium, or they may be restricted to certain zones, as in Vorticella (p. 37). The cilia beat in a coördinated fashion and thus propel the animal through the surrounding liquid medium. In some of the Infusoria larger filaments, termed CIRRI, are formed by a fusion of the cilia, and these are used in crawling along on solid surfaces. Various ciliated cells are also present in the higher animal forms. In the latter case the cilia are confined to the exposed surface of the cell. These ciliated cells, grouped together, form a ciliated surface which is present as a lining in many ducts where the beat of the cilia produces a current for the movement of various liquids (W. f. 7, C).

In the higher animals, the power of movement is largely centered in the contractile muscle tissue which is differentiated for this purpose. Muscle tissue is composed of highly specialized cells which act in unison when stimulated, and thus bring about a movement of the muscle as a whole. In the final analysis, however, it is the intracellular cytoplasmic movement in each muscle cell which brings about the mass movement of the muscle as a whole, just as it is in any movement of protoplasm.

II. AMOEBA

The forms of animal life classified among the Protozoa constitute the most primitive group of the Animal Kingdom (W. p. 414). Included among the Protozoa are some 10,000 species, and one of the most interesting of all these is the form known as Amoeba. The interest in Amoeba is due chiefly to the fact that it is one of the simplest of organisms. In fact its structure is such that, under the microscope, one can here carefully observe and study a tiny bit of that amazingly versatile material which composes the cells of all organisms, namely, protoplasm, stripped of all those structural features which tend to obscure it in the higher forms of life. The Amoeba, therefore, is well suited for use in beginning a study of protoplasm and its associated phenomena.

A. Structure of an Amoeba

Under the higher power of the microscope a living Amoeba is revealed as a tiny irregular drop of material which is almost transparent (W. f. 2). Continued observation shows very shortly that a streaming, or flowing, movement is continually occurring, and this results in a quite rapid change in the shape of the animal as well as a slow movement of the entire cell. In its very simple form, the Amoeba lacks one of the features which, as we have seen, is characteristic of cellular structure, namely, a definite cell wall. The protoplasm, however, is differentiated into the cytoplasm and nucleus which constitute the essential parts of cellular structure. Furthermore, the cytoplasm of an Amoeba consists of a thin outer layer of ECTOPLASM which serves as a low type of protective layer, and an inner layer of ENDOPLASM which constitutes the bulk of the animal.

The ectoplasm shows a clear, homogeneous structure and, in an active specimen, may be described as a rather viscous, transparent liquid. It slowly flows in various directions, depending upon the environment. This flowing movement results in the formation of irregular surface projections, known as PSEUDOPODIA (singular PSEUDOPODIUM). It is by means of the flowing movement, with the consequent formation of pseudopodia, that the animal moves. A movement of this type, as noted above, is known as amoeboid movement. The exact nature of amoeboid movement is not fully established, even though it has been the subject of a large amount of research work (W. f. 2, *3*).

The endoplasm, in comparison with the ectoplasm, is not so viscid a substance and, therefore, it flows more readily. The observations of living Amoebae show, however, that in the formation of pseudopodia the flowing movement starts first in the ectoplasm, and later the endoplasm rapidly streams into the ectoplasmic region where the pseudopodium is being formed. The endoplasm is not so transparent as the ectoplasm, and a microscopic study with the proper type of illumination gives evidence that it is not a homogeneous material. It is generally believed that the endoplasm consists of a basic ground substance in which innumerable minute particles are suspended. In addition to these particles, which apparently form a fundamental constituent of the endoplasm, it will be found that there are also many larger particles of various kinds, shapes, and sizes present. For the most part these are transient, non-living metaplasmic materials such as undigested particles of food, indigestible refuse which has not been expelled, etc. (W. f. 2, *5*).

The endoplasm contains a number of other structures, the most important being the nucleus, which is an essential part of all cells (W. f. 2, *2*). There is also a single CONTRACTILE VACUOLE which collects and expels the liquid, and possibly gaseous, wastes resulting from the breaking down of living material, as well as the excess water taken

in with food. Numerous GASTRIC VACUOLES are present in which the particles of food that have been taken into the animal are being digested. The gastric vacuoles are not permanent structures; the number at any time depends upon the amount of food material which is undergoing digestion (W. f. 2, *4*).

When it comes to the determination of the exact physical structure of protoplasm, whether it be from an Amoeba or from a Man, the problem becomes very difficult — in fact, so difficult that the solution is not apparent at the present time, even though it has been, and still is, the subject of almost unlimited thought and investigation by the ablest scientists. The determination of the exact character of protoplasmic structure is definitely limited by the fact that it cannot be subjected to intensive analytical methods without thereby destroying the primary object of the investigation, namely, the quality we call life. The dead material, which was formerly protoplasm, can, of course, be subjected to all kinds of analysis, but such analyses do not reveal the basic secrets of protoplasmic structure (W. pp. 7–10).

B. Life Processes of an Amoeba

1. *Nutrition*

One of the fundamental characteristics of living organisms is the power to take in certain materials from the outside environment and either use them at once to supply energy for the life processes, or convert them into the actual, living protoplasm of the body. The nutrition of an animal is designated as HOLOZOIC, and involves destructive chemical processes in which various types of complex foodstuffs are broken down, and the resulting materials utilized in various ways. This type of nutrition is essentially different from the nutrition of a green plant, which is designated as HOLOPHYTIC. In the latter case simple inorganic substances are

taken from the environment and combined to form complex foodstuffs which plant or animal tissues can assimilate. In the Amoeba, of course, the holozoic type of nutrition obtains, and this animal has the power to carry on this process in essentially the same way as do the highest types of animal organisms, the difference being that the single-celled animal, lacking the highly developed nutritive systems of the higher forms, does the work with much simpler apparatus (W. pp. 34–37, 41–42).

The HOLOZOIC nutrition of animals involves several stages, namely, the capture and ingestion of food, its digestion and assimilation, and, finally, the egestion of the indigestible refuse. These various steps in the nutrition of Amoeba may next be considered.

In the environment of the Amoeba there are organic materials of various kinds which the animal is able to utilize as food. Among these may be noted unicellular plants, such as the Bacteria and Diatoms, filamentous Algae, other forms of Protozoa, and organic débris of many kinds. The Amoeba has only one method for securing all types of food material. This consists of flowing around the food particle by means of the pseudopodia. When contact has occurred with a food particle, the process of ingestion begins at once: All regions of the ectoplasm of the Amoeba can carry out this combined process of capture and ingestion. Apparently it is the chance contact which determines the particular part of the ectoplasm which is to act as the temporary organ for capturing a particular food particle and also as the temporary mouth for engulfing it.

An Amoeba, of course, comes into contact with many particles of inorganic material, such as grains of sand, which cannot be utilized as food. It can generally be shown in such cases that the ectoplasm of the Amoeba differentiates between the materials which are suitable for food and other materials which cannot be so used. Thus, when an Amoeba comes into contact with a grain of sand, instead of engulfing

it, the flowing movement and pseudopod formation in that direction ceases, and a movement is initiated in another direction, which avoids the undesirable material.

A food particle having been ingested by the ectoplasm then passes into the endoplasm, becomes surrounded by a small amount of fluid taken in with it, and constitutes a gastric vacuole in which digestion takes place. The portion of endoplasm which surrounds the food material apparently becomes temporarily specialized for the work of digestion and is able to secrete certain chemical substances, known as ENZYMES, which are believed to be of the same nature as those secreted in higher forms of animals by the glands in the walls of the alimentary tract. It is these enzymes which digest the food. Digestion, in all forms of animals, may be defined as a process whereby complex food materials are rendered soluble and capable of being assimilated by the cell or cells, and thus built up into the protoplasm. This is just what happens to the food in the gastric vacuoles of an Amoeba.

The process of assimilation of the digested material in Amoeba and in other unicellular forms is a comparatively simple one, for the food as it is digested in the gastric vacuole passes directly into the surrounding endoplasm and is at once employed by, or built up into, the living matter. In practically all kinds of food a certain amount of indigestible material is taken into the body, and this must be eliminated. Such material has never been a part of the organism; it is only a temporary inclusion. The process of elimination of such material is known as EGESTION and is to be distinguished from the process of EXCRETION. The latter is concerned with getting rid of waste materials that have actually played a part in the life of the organism. In the Amoeba there is no specialized structure for ridding the body of the refuse from digestion, and it can be eliminated through the ectoplasm in the area which happens to be nearest to the gastric vacuole at the time digestion is completed.

2. *Respiration*

Respiratory activities — involving the intake of oxygen which is necessary for the metabolic processes, and the outgo of carbon dioxide which has been formed as a result of the destructive metabolic processes — are present in all organisms. It can be regarded as a double process; on the one hand, the supplying of oxygen, which is a phase of nutrition, and on the other hand, the elimination of carbon dioxide, which is a phase of excretion. In the Amoeba, the entire surface of the animal serves as a medium through which this essential interchange of gases takes place (W. pp. 37, 43).

3. *Excretion*

The process of nutrition in Amoeba, considered above, results in the continual supplying to the animal of food material which is utilized either as a source of immediate energy, for repairing the continual processes of waste, or for the growth of the animal by intussusception. As long as there is life, the protoplasm is continually being torn down, and, if life is to exist, it must be replaced just as continually by the assimilation of food material. The main products, resulting from the destruction of protoplasm, consist of carbon dioxide, noted above, water, and urea; the latter containing nitrogenous materials.

The nitrogenous wastes of Amoeba are excreted through the surface ectoplasm to some extent and also by means of a specialized structure, the contractile vacuole, into which the wastes from the cytoplasm continually drain. As a result the vacuole enlarges. When a certain size is reached, the surrounding endoplasm contracts, and the wastes are forced out of the animal into the surrounding liquid environment through whatever portion of the ectoplasm happens to be nearest to the contractile vacuole at the time. By this contraction of the surrounding endoplasm, the cavity of the

contractile vacuole is temporarily eliminated, but in a few moments the waste materials will again be present in a sufficient quantity to bring about a reappearance of the vacuole. A little later, the contractile vacuole having again attained the maximum size, a contraction of the endoplasm takes place with a consequent expulsion of the liquid contents as before described. It is probable that the contractile vacuole also plays a part as a respiratory organ.

4. *Reproduction*

When the food supply of an Amoeba is plentiful, so that the animal can ingest, digest, and assimilate food material in such an amount that the katabolic wastes are more than met, growth results. If this process of growth were able to continue indefinitely, Amoebae of enormous size would soon develop. For some reason, however, Amoebae and other animals are limited, although there is some variation, to a certain maximum size which is characteristic of the particular species. When this limit is reached in an Amoeba, the unicellular animal divides by mitosis into two separate individuals each of which when first formed is one-half the size of the parent. The two animals begin at once to assimilate food material in sufficient quantities to cause growth, and in a few hours each has attained the normal size. Reproduction by division may again take place, so that within the space of a few hours four independent Amoebae will thus have arisen from the original parent animal.

If the environmental conditions continue to be favorable, there will be in the course of a few days thousands of Amoebae. The process could apparently continue, if the food supply held out and there were no other inhibiting environmental influences, until the universe was filled with a mass of amoebic protoplasm. It is a question, however, whether any protozoan cell can continue to divide indefinitely without the

occurrence at certain intervals of some type of a reorganization of the nuclear material. Although our knowledge of the life history of Amoeba has not as yet been fully established, evidence is at hand which indicates that the periods of simple cell division are dependent upon an internal reorganization process of some type. This question is considered in greater detail in the study of the protozoan form, Paramecium.

5. *Adaptation*

An Amoeba has the power of adapting itself to its environment in response to various kinds of stimuli which it receives. The protoplasm of which it is composed may be aroused or irritated by a number of external factors such as light, temperature, electricity, chemical stimuli, and contact. Any part of the ectoplasm of Amoeba is able to receive these stimuli and to respond to them; it is all irritable material. This is different from what is found in higher forms of animals where a specialized nerve tissue is present, which is connected with various types of sense organs adapted for receiving different kinds of stimuli.

The capture of food and the rejection of unsuitable materials by an Amoeba, which have been noted above, may be taken as examples of the ability of the ectoplasm of this animal to receive and be influenced by external stimuli. It is probable that food is secured in two ways: first, by the stimulus received through a chance contact with a food particle and, second, as a result of a chemical stimulus. There is some evidence to show that the Amoeba and other species of Protozoa have the ability to 'sense' food at a distance and then move more or less directly toward it.

III. PLEUROCOCCUS [1]

In the Plant Kingdom, just as in the Animal Kingdom, there is a group of primitive unicellular forms. The unicellular plants are frequently referred to as the Protophyta. Included in this group are such forms as Pleurococcus and Sphaerella, which have the typical nutrition of green plants, and also colorless types like the Bacteria and Yeast, which, lacking chlorophyll, have to depend for their nutrition upon more complex food materials.

Pleurococcus is widely distributed and easily secured. It forms a greenish covering on the bark of trees, on flower pots, and on many other suitable surfaces where a rather moist habitat is provided. The greenish covering, when examined microscopically, is found to consist of an enormous number of tiny cells, each of which is able to carry on an independent existence. Our present interest in Pleurococcus, just as in the previous study of Amoeba, lies in its extreme simplicity of structure. Here in this minute cell — although it lacks all the specialized organs of higher plants, such as roots, stem, and leaves — are concentrated all the characteristic and essential life processes of the green plants, however high in development they may be: metabolism, with the superimposed and absolutely fundamental process of synthetic food formation, respiration, growth, reproduction — all are present.

A. Structure of Pleurococcus

The single cells of Pleurococcus are revealed under the microscope as tiny, green, more or less spherical bodies.

[1] Woodruff, pp. 30–38.

Each cell possesses a comparatively heavy, rigid cell wall, composed of cellulose. The enclosed protoplast is differentiated into cytoplasm, nucleus, and chloroplastid. The nucleus is spherical with a well-defined nuclear membrane and, as a rule, is centrally located. The chloroplastid is large and varies in shape. These few parts, giving every appearance of structural simplicity, are all that can be seen in this cell which constitutes the entire body of this unicellular green plant, and yet in it lies not only the profound mystery of the organization of protoplasm in general, but in addition the unique power, possessed only by green plants, to manufacture foodstuffs from the simple inorganic materials.

B. Life Processes of Pleurococcus

1. *Nutrition*

The nutrition of Pleurococcus, based as it is on the presence in the chloroplastids of the green-colored pigment, chlorophyll, may be taken as a typical example of the constructive holophytic type of nutrition of green plants.

In the surrounding environment of a Pleurococcus cell are all the simple inorganic substances necessary for the synthesis of those foodstuffs which are essential for the nourishment of protoplasm. As there are no openings through the cell wall these inorganic materials cannot be ingested as in an Amoeba, and thus all interchange of substances between Pleurococcus and its environment must take place by passing directly through the cell wall. This process is believed to follow the laws of diffusion, and to be governed in general by the layer of cytoplasm lining the cell wall. The substances taken in for use in photosynthesis consist of carbon dioxide and water; the latter carrying in solution the various inorganic salts, particularly nitrates, which are necessary for the formation of the more complex foodstuffs.

In the cell cytoplasm it is believed that the first step is the uniting of the carbon dioxide and water to form a sugar. This process involves the action of the chlorophyll together with the energy received from the sun. The sugar formed by the synthesis of the carbon dioxide and water having taken place, the product may be utilized at once by the plant protoplasm (1) to secure energy, or (2) it may be changed to a starch and stored for later use, or (3) the proportion of oxygen present in either the sugar or starch may be decreased, and thereby the food changed from a CARBOHYDRATE into a fat, or HYDROCARBON, or finally, (4) the carbohydrate may be built up into the more complex food materials, PROTEINS, by the addition of nitrates and other inorganic materials present, in solution, in the water taken into the Pleurococcus cells. There is a question as to whether the protein formation occurs as a part of the photosynthetic action or whether it is a later process brought about in some other way (W. pp. 35–38).

2. *Respiration*

The process of respiration which is continually occurring in all living organisms is obscured in green plants in sunlight by the reverse process of photosynthesis, in which oxygen is liberated and carbon dioxide taken in. Thus a green plant in which photosynthesis is occurring not only uses all of the carbon dioxide resulting from its own katabolic activities, but it also takes in an extra supply from the environment. At the same time it gives off the excess oxygen. At night when there is no sunlight, and photosynthesis has to cease, the process of respiration, which has been going on all the time and will continue to go on as long as the plant lives, becomes evident, and then the green plant, just like an animal, actually gives off carbon dioxide and takes in oxygen.

3. *Reproduction*

So far as is known reproduction in Pleurococcus is entirely an asexual process, in which the cells, when they have attained a certain size, divide to form two equal-sized daughter-cells. In many cases the cells thus formed remain temporarily attached. Thus a group of several attached cells is formed. This condition is believed to foreshadow the permanent multicellular condition in higher plants. However, in Pleurococcus, after a time the attachment material between two cells is dissolved, probably by enzyme action, and the cells separate entirely.

IV. EUGLENA

Euglena is a common example of a group of unicellular whip-bearing, or flagellated, organisms, known as the Mastigophora, or, more commonly, as the Flagellates (W. fs. 16–18, 182). A number of species here classified, including Euglena, possess chlorophyll — that remarkable food-synthesizing agent which, as has been noted, is characteristic of green plants. This fact is given great weight by many authorities, and they regard such forms as plants, placing them in close relationship with the unicellular Algae, such as Sphaerella. Other authorities, notwithstanding the plant-like nutrition, regard Euglena and related forms as animals because their general structure is very similar to undeniable unicellular animals. In other words, they regard Euglena as an animal which in some way has acquired a plant-like type of nutrition. For the present, Euglena may be considered as a border-line, or transitional, form, showing a close relationship to the Protozoa in its structure and in various other ways, and to the green plants in its nutrition.

Thus it is evident that in certain of the lower forms of life, the characteristics, which seem unmistakably to differentiate higher plants and animals, disappear, so that it becomes impossible, when considering the numerous examples of these border-line forms, to say definitely that they are either plant or animal. They partake of the characters of both.

A. Structure of Euglena

Euglena, although microscopic, is generally larger in size than an Amoeba, and it also shows a somewhat higher type

of organization than does the latter. The outer surface of the body is covered by a delicate, striated cell wall which is formed as a secretion by the underlying ectoplasm. An active Euglena exhibits peculiar squirming, or euglenoid, movements, during which the shape of the cell varies greatly, ranging from nearly spherical to a typical cigar-shape. These changes in shape may possibly be due to the fact that the cell wall or pellicle is very thin and, therefore, does not possess sufficient rigidity to hold the rather fluid ectoplasm in a constant shape. The cell wall, however, is sufficient to maintain a regular body outline so that the formation of irregular projecting pseudopodia does not occur, as it does in an Amoeba (W. f. 16, C).

Projecting from the somewhat blunt anterior end of Euglena is a delicate, vibratile filament, or FLAGELLUM. It arises from a number of very fine fibrils, present in the ectoplasm near the anterior end of the body, which are twisted together to form the flagellum. The flagellum is attached in a depression in the ectoplasm, known as the GULLET. In many of the Protozoa the gullet extends down into the endoplasm and serves as a passage for food particles. In Euglena, however, the gullet apparently has nothing to do with the process of obtaining food. In an active individual the flagellum is generally continually vibrating with such great rapidity that it is difficult to see. It serves as an organ of locomotion and, as a result of its spiral movement, the organism is drawn with considerable speed through the water.

The endoplasm of Euglena, which makes up the greater part of the animal, contains a number of interesting structures. At the anterior end, just back of the so-called gullet, is the contractile vacuole. This structure does not have the simplicity that characterized the single contractile vacuole of Amoeba. It consists in Euglena of a large central reservoir which is believed to empty into the gullet. Around the edge of it are a number of tiny contractile vacuoles which dis-

charge the liquid wastes into the central reservoir (W. f. 16, C, *cv*, *R*).

Situated close to the reservoir of the contractile vacuoles is a spherical body of great interest, known as the EYE SPOT, or STIGMA, which consists of a tiny bit of cytoplasm containing reddish-colored pigment (HAEMATOCHROME). It is known that this region in Euglena is sensitive to light rays, and thereby enables the animal to find the place in its environment which is best adapted for its photosynthetic nutritive processes. It is believed that this reaction to light in Euglena is centered in the pigmented stigma — in other words, that it is a primitive type of light-receiving apparatus (W. f. 16, C, *S*).

The chlorophyll in Euglena is contained in a number of disc-shaped chloroplastids which are scattered through the endoplasm. Pyrenoids, which serve as storehouses for the manufactured food, can also be demonstrated in some individuals (W. f. 16, C, *Ch*).

The large nucleus of Euglena lies embedded in the endoplasm posterior to the center of the animal (W. f. 16 *C*, *N*).

B. Life Processes of Euglena

1. *Nutrition*

Euglena not only has holophytic nutrition in which complex foodstuffs are manufactured synthetically, as in the green plants, but it has also been shown that Euglena, when placed in an environment containing organic materials in solution, can nourish itself and thrive in the absence of sunlight. It is apparent in the latter condition that Euglena is able to make use of another type of nutrition, known as SAPROPHYTIC or SAPROZOIC, — the exact term depending upon whether the organism is regarded as a plant or an animal, — in which complex food materials in solution are taken through the cell wall by diffusion.

There does not appear to be any evidence that Euglena ever receives any nutriment by the holozoic method of nutrition, such as was studied in Amoeba, in which solid particles of food are ingested and then acted upon by secreted digestive elements in order to render them soluble and capable of being assimilated.

The elimination of the protoplasmic wastes of Euglena occurs, as in Amoeba, by the interchange of gases through the cell wall, and the elimination of liquid wastes by means of the contractile vacuole.

2. *Reproduction*

Under favorable environmental conditions, when a Euglena has reached a certain volume, reproduction by simple BINARY FISSION occurs, as in Amoeba, and two daughter-cells result. The cell body of Euglena, and other related forms, always divides longitudinally, beginning at the anterior end. Very shortly after the division, if the conditions are favorable, the daughter-cells attain the normal structural organization and also the size of a typical Euglena.

When the environmental conditions of Euglena are unfavorable, due to a lack of moisture or other factors, it has the power of ENCYSTING, a process which is quite common among many species of the Protozoa and Protophyta. An animal just previous to encystment becomes quiescent and soon assumes a spherical shape. The ectoplasm then secretes a resistant cyst wall which entirely encloses it. In this condition the organism is dormant and is able to withstand unfavorable environmental conditions. When the latter are again favorable the cyst wall is dissolved, and the Euglena once more assumes an active life. In many cases cyst formation is followed by reproduction, for during encystment one or more divisions of the cell body may occur, so that when the cyst wall is later dissolved, two or more individuals escape and begin an active, free-swimming existence.

3. *Adaptation*

The stigma in Euglena, as has been stated above, is believed to be sensitive to light rays. Thus the organism is able to attain the particular location in any given environment which is best adapted for carrying on the photosynthetic processes. In a culture of Euglena it will be found, for example, that the individuals, in general, move toward the source of light. However, direct sunlight does not represent the best condition, and may even be fatal. If, therefore, one side of the culture is dark and the other side is in the direct sunlight, it will be found that the organisms tend to congregate in an intermediate zone between the two extremes. This particular region is the one with optimum conditions for photosynthesis. A response to light by an organism is spoken of as PHOTOTROPISM, and Euglena, since it moves toward the light, is said to be positively phototropic.

V. PARAMECIUM [1]

PARAMECIUM is a widely distributed representative of a group of ciliated Protozoa, known as the Infusoria. Various species of Paramecium are commonly found in fresh-water cultures, such as hay infusions, in almost all regions of the world. As has been previously noted (p. 8), the coördinated movements of the cilia in this animal furnish a very efficient method of locomotion. Infusoria are typically free-swimming types with a much greater specialization of the different parts of the cell than is present in Amoeba and Euglena. Thus within the limits of a single microscopic cell, which constitutes the entire body, structures are provided for carrying on numerous vital activities such as nutrition, excretion, reproduction, locomotion, and defence. Paramecium, therefore, provides a splendid example of the high specialization which may be attained in a unicellular animal.

A. STRUCTURE OF PARAMECIUM

When a drop of water containing Paramecia is examined with the naked eye, it will be found, with careful observation, that the animals can just barely be seen as tiny, rapidly moving bodies. A microscopic study shows that Paramecium, when viewed as a flat surface, has somewhat the shape of a shoe sole, and on this account it is often referred to as the "slipper animalcule" (W. f. 10). When a transverse section through the animal is studied, it is found to be nearly circular in outline. In swimming it will be noted, contrary to what might be expected, that the animal normally moves with the more blunt end pointed forward. This end

[1] Woodruff, pp. 39–43, 242–248.

is regarded as the anterior end of the body, and the opposite, more pointed extremity as the posterior end (W. f. 10).

Beginning at the blunt anterior end, and continuing posteriorly to a point slightly back of the middle of the body, is a depression, known as the PERISTOME, which gives the animal an asymmetrical appearance (W. f. 10, *j*). It becomes deeper as it passes posteriorly, and finally ends in a definite tube, the GULLET, which lies quite deep in the cytoplasm (W. f. 10, *d*). The surface of the animal, including the peristome, is uniformly covered with fine, hair-like filaments, the CILIA, which continually beat in the water in a coördinated manner and thus enable the animal to swim in a rapid, vigorous fashion. Some of them also aid in the capture of food, by driving a current of water along the peristome (W. f. 10, *l*, *j*).

The transparent ECTOPLASM of Paramecium is much more rigid than the ectoplasm of either Amoeba or Euglena, so that normally the animal maintains a definite shape. However, when an individual is pressed against pieces of débris or under the influence of various other environmental conditions, a considerable variation in shape takes place. Enclosing the ectoplasm of Paramecium is a thin, secreted cell wall, the PELLICLE, which shows very fine regular markings, or striations, on the surface. Innumerable fine strands of ectoplasm project through the pellicle. These constitute the cilia which form a uniform covering over the surface of the animal.

Embedded in the ectoplasm is a single layer of highly differentiated, flask-shaped bodies, known as the TRICHOCYSTS. They lie with their long axes perpendicular to the surface of the ectoplasm. The base of the structure is toward the interior of the animal, and the other end opens through the ectoplasm to the exterior (W. f. 10, *k*). These trichocysts are filled with a fluid which hardens and becomes thread-like when it is expelled into the water. The discharge of the trichocysts can be brought about experimentally by

adding a little dilute acid to the culture medium and thus irritating the Paramecia. In some species of Protozoa it has been found that the trichocysts have a paralyzing effect upon other living organisms, and they are therefore regarded as weapons useful either in the capture of other animals for food or in the repelling of attacks by enemies. In Paramecium, however, the function of these bodies is not definitely known.

The ENDOPLASM of Paramecium is, as has been found to be the case in other forms, somewhat less viscous than the ectoplasm (W. f. 10, *h*). It also contains many granules of various sizes, some of which are constituent parts of the cytoplasm, while others are merely temporary metaplasmic particles. The endoplasm also contains numerous GASTRIC VACUOLES (W. f. 10, *c*, *g*) and a characteristic nuclear apparatus composed of a large MACRONUCLEUS and a small MICRONUCLEUS,[1] the latter lying on or near the macronucleus (W. f. 10, *b*, *i*). Lying between the ectoplasm and endoplasm are two CONTRACTILE VACUOLES, one near each end of the animal (W. f. 10, *a*, *f*). Each contractile vacuole consists of a large central spherical vacuole and a number of radiating canals which open into it; the whole forming a star-shaped structure (W. f. 10, *a*).

B. Life Processes of Paramecium

1. *Nutrition*

Paramecium exhibits a typical holozoic type of nutrition. The food consists for the most part of various kinds of Bacteria together with a number of tiny species of Flagellates, all of which are obtained from the surrounding fluid medium. The cilia lining the peristome play an important rôle in capturing the food. The coördinated beat of these cilia is so directed as to cause a continuous current of water, containing the food-materials, to sweep down to the posterior end

[1] Woodruff, p. 40, *footnote*.

of the peristome. Here the particles pass through the 'mouth' opening into the tubular gullet. The particles of food collect at the posterior end of the gullet and form a gastric vacuole in the endoplasm which, when it has attained a certain size as a result of the continued increase in the number of captured food particles, is detached from the end of the gullet. This apparently takes place as the result of a contraction of the surrounding endoplasm. As soon as one gastric vacuole is detached from the end of the gullet another one at once begins to form in the same place.

The fully formed and detached gastric vacuole, as a result of a continual streaming movement, termed CYCLOSIS, of the endoplasm, is moved in a definite path through the body. It is first carried backward with the endoplasmic current and almost reaches the posterior end of the animal. It is then carried forward along the dorsal surface to the anterior end of the body, where the protoplasmic motion is again reversed, and the gastric vacuole passes first ventrally and then posteriorly toward a definite ANAL SPOT which is situated on the ventral surface of the body, near the posterior end. Emphasis should be laid upon the fact that this process of cyclosis, which results in a definite orderly movement of the gastric vacuoles through the endoplasm of Paramecium, is due to a streaming of the endoplasm, the food vacuoles playing an entirely passive rôle. A similar movement (p. 7) has already been noted in the cells of the green plant, Elodea.

During this movement of the gastric vacuoles, the process of digestion of the food material takes place. The results of experimental studies show that the chemical actions, which take place in the digestion of food in the gastric vacuoles of Paramecium and in many other Protozoa, are fundamentally the same as take place in the digestion of food in higher forms of animal life. In all cases the food is acted on by the secreted enzymes which render it soluble and capable of being assimilated by the protoplasm.

Paramecium does not show a definite selection of food such

as occurs in Amoeba. Almost any minute particle, whether it be food or not, which comes in the range of the current of water caused by the beat of the cilia in the peristome may be carried along and deposited in a food vacuole. This can be well illustrated by adding a small amount of an indigestible substance, such as powdered carmine or other finely ground material, to the fluid which contains Paramecia. A microscopic study of such a preparation shows that the indigestible carmine particles are collected to form gastric vacuoles in just the same way as are food particles. The carmine-filled gastric vacuoles are also detached from the end of the gullet and carried in the normal way through the endoplasm, finally ending at the anal spot, from which the carmine particles are egested.

2. *Respiration and Excretion*

We turn now to a consideration of the methods by which the wastes resulting from the continual breaking down of protoplasm are eliminated. It may be stated at once that the same methods are used in Paramecium as in Amoeba and Euglena; that is, the interchange of gases through the surface of the body, and the excretion of the liquid wastes by means of the two contractile vacuoles.

The contractile vacuoles in Paramecium maintain practically constant positions, one near the anterior end and the other near the posterior end of the body. The liquid wastes first collect in the radiating canals which surround each contractile vacuole. They pass from the former into the central cavity, from which they are expelled to the exterior later by the contraction of the surrounding endoplasm. The two vacuoles, as a rule, contract alternately.

3. *Reproduction*

In Paramecium, just as in the other unicellular forms, reproduction occurs as a result of a division of the cell into

two daughter-cells. Paramecium and other Infusoria divide transversely, whereas in Euglena and other Flagellates the division is longitudinal (W. f. 11).

In the cell division of Paramecium there is, first, a division of the micronucleus into two equal parts. Then the macronucleus, having elongated somewhat, also divides into halves. Following this, the cytoplasm in the center of the animal begins to constrict transversely. The constriction continues to deepen, and in the course of an hour or so, the animal is completely divided into two daughter-cells, each of which, although at first only one-half the normal size, nevertheless contains the normal nuclear structure and most of the other characteristic features. Structural modifications are occurring synchronously with the division of the nuclei and the cell body, so that when the two halves separate, the animal formed from the anterior half has a newly formed posterior end, and the animal resulting from the posterior half has a newly formed anterior end with the various specialized structures, such as the peristome and contractile vacuole. This process of cell division normally may take place two or three times within twenty-four hours.

The life history of Paramecium, however, is not so simple as might be thought from the above description of reproduction by cell division, for there is strong evidence that after reproduction has gone on for a considerable number of generations in this manner, a reorganization of the cytoplasmic and nuclear material typically occurs. It is probable that this reorganization can take place either by ENDOMIXIS or by CONJUGATION.

ENDOMIXIS. If Paramecia are kept under certain culture conditions in which they can be observed day by day, it will be found that a lowering of the division, or reproduction, rate occurs at quite regular intervals. This reduction is apparently independent of the food or of other environmental conditions. In other words, although there is plenty of food, the animals are not able to reproduce as rapidly as

usual, due, supposedly, to some internal factor or factors. A depression of this type is the external evidence of the beginning of a periodic process of intracellular reorganization and adjustment between the cytoplasm and nuclear material of the animal, known as endomixis (W. f. 131).

A study of the process of endomixis in the species known as *Paramecium aurelia*, which has normally two micronuclei, shows that: (1) each of the micronuclei divides twice to form a total of eight micronuclei (W. f. 131, *C*); (2) the macronucleus fragments and finally is completely broken down and dissolved in the cytoplasm; (3) six out of eight of the newly formed micronuclei degenerate (W. f. 131, *D*); (4) the cell divides, and one micronucleus goes to each daughter-cell (W. f. 131, *E*); (5) the micronucleus in each cell divides twice to form four nuclei (W. f. 131, *G*), two of which become macronuclei and two micronuclei (W. f. 131, *H*); (6) each of the two cells now divides, thus giving four normal cells, each of which has a macronucleus and two micronuclei (W. f. 131, *J*).

From the above description, it can be seen that the process of endomixis brings about a complete, periodic reorganization of the entire nuclear apparatus of an animal. When the process has been completed, the normal rate of division, which has been temporarily depressed, is again established, and the animal — if the environmental conditions are suitable — can grow and reproduce with the normal rapidity for some weeks until the onset of the next endomictic period.

CONJUGATION. Considering next the process of conjugation, which apparently is of almost universal occurrence among the Protozoa, it should be emphasized that, while it is a process of nuclear and cytoplasmic reorganization, it also involves, first, an interchange of nuclear material between two animals and, second, the fusion (AMPHIMIXIS) in each animal of the nuclear material received with a portion of the nuclear material already there to form a **fertilization nucleus, or SYNKARYON.**

The first step in the process of conjugation in Paramecium is the meeting and temporary fusion of two animals. This normally occurs in such a way as to involve a considerable portion of the oral surfaces (W. f. 12). Thus a temporary protoplasmic bridge is formed between the animals. Coincident with this external fusion of the two animals, a series of internal, nuclear-reorganization phenomena begin in each animal which are of the same general character as in endomixis, and which in *Paramecium aurelia* may be outlined as follows (W. f. 130):

(1) The two micronuclei in each animal become somewhat enlarged, and two mitotic divisions occur, resulting in the formation of eight micronuclei in each animal (W. f. 130, *C*). The macronucleus, which plays no apparent part in conjugation, degenerates and entirely disappears.

(2) Seven of the eight newly formed micronuclei in each animal degenerate (W. f. 130, *D*), and the remaining one divides again to form two bodies, known as PRONUCLEI (W. f. 130, *F*).

(3) The two pronuclei in each animal exhibit a different behavior; one of them (STATIONARY PRONUCLEUS) remains in the animal where it was formed, but the other (MIGRATORY PRONUCLEUS) moves across the protoplasmic bridge into the other animal (W. f. 130, *F*), where it permanently fuses (FERTILIZATION) with the stationary pronucleus there present to form the synkaryon (W. f. 130, *G*).

(4) The exchange of nuclear material having been effected, the two animals separate. In each exconjugant the new nuclear apparatus is then built up by the division and differentiation of the synkaryon. It divides twice in each exconjugant to form four micronuclei (W. f. 130, *I*), two of which remain as micronuclei and two enlarge to form macronuclei (W. f. 130, *J*). The two micronuclei in each exconjugant then divide (W. f. 130, *K*). This is followed by the division of each exconjugant into two normal cells, each with a macronucleus and two micronuclei (W. f.

130, *K*). A period of regular cell division now follows (W. f. 115, *A*).

4. *Adaptation*

The fact that Paramecium, because of its highly developed, ciliary locomotor apparatus, is able to move in any direction with considerable rapidity, makes it a valuable animal for studying its reaction, or "motor response" to various kinds of external stimuli. The latter may be caused by various changes in the environment as a result of the action of chemical, electrical, photic, or thermal phenomena. If, for example, a drop of some unfavorable fluid is added to the culture medium containing Paramecia, when the animals come into contact with it, they will give a characteristic "avoiding reaction." In such a case an animal first backs off a little way from the unsuitable region, changes the course of direction somewhat, and then moves forward in an endeavor to avoid the source of irritation. If the direction taken accomplishes this, then the animal will continue its course ahead until some other external factor intervenes to bring about a change of direction. If the direction taken again brings the animal into contact with the unfavorable medium, the avoiding reaction is again given, and another course is tried (W. pp. 340–344).

In locomotion, the cilia covering the body of the animal exhibit a beautifully coördinated, beating movement. Their action normally drives the animal forward, but by a reversal of the ciliary action, the animal is able to move backward with equal rapidity. It is obvious, of course, that the movements of all the cilia must be in unison if a definite progression of the animal is to be obtained. It is an interesting problem to determine how the beats of almost innumerable cilia can be controlled in such a way as to bring uniformity of action, or how the action of all the cilia can be reversed suddenly, and the animal thereby driven in the opposite direction. It

would seem as if there must of necessity be some sort of complicated controlling mechanism to bring about such coördination, and, as a matter of fact, evidence has recently been found in several species of Ciliates, including Paramecium, which goes to show that a coördinating "neuromotor" apparatus is present. Presumably this apparatus functions somewhat like the nervous system in the higher forms of animals.

VI. VORTICELLA

The Ciliates, in addition to the type already noted, include a group of interesting forms, of which Vorticella may be taken as a typical example. These animals are typically bell-shaped, and the 'handle' to the bell consists of a comparatively long, contractile stalk. The cilia are, in general, restricted to a definite anterior region where they aid, as in Paramecium, in the capture of food particles. Our interest in Vorticella lies chiefly in the complexity of its structure, and particularly in the fact that differentiated contractile fibers are present. Thus there is found in this protozoan form the forerunner of the specialized contractile elements, the muscle tissue, of the higher animals. Vorticella is a single form, but there are a number of other closely related types which are colonial. In such cases, several individuals are attached to a common contractile stalk.

A. Structure of Vorticella

Vorticella, because of its shape, is often referred to as the "bell-animalcule." Projecting from the apex of the bell-shaped body is a long contractile stalk which serves to attach the animal to any near-by piece of solid matter. The large, flaring bottom of the bell is almost filled with a circular structure, known as the disc. The edge, or EPISTOME, of the disc is in close contact with the lower edge, or PERISTOME, of the body around most of its circumference. At one point, however, the epistome and peristome are separated, and a considerable space is left between them, which is known as the VESTIBULE. In this vestibule, the food particles are first collected, and then pass from it through a mouth opening

into the gullet. Also the liquid wastes of the animal are given off into the vestibule and thence passed to the exterior. The body of Vorticella is made up of an outer layer of ectoplasm and an inner mass of endoplasm. A secreted pellicle is present and forms a covering over the entire body.

The endoplasm of Vorticella, as in other protozoan forms, makes up the great mass of the bell-shaped body. It contains numerous gastric vacuoles, a large U-shaped macronucleus, and a small micronucleus (W. f. 16, D, *Na*, *N*, *Nn*). There is usually a single, large contractile vacuole (W. f. 16, D, *Cv*).

Axial Filament. In the stalk, entirely enclosed by the pellicle, is an interesting structure, the axial filament. This is a specialized contractile element and consists of a great number of fine, contractile fibers, the myonemes. These arise in the ectoplasm of the bell and converge to form the axial filament in the stalk. The myonemes are of particular interest, because they represent the lowest type of differentiated contractile fibers which may be compared to the contractile muscular elements of higher animals (W. f. 16, D, *Fi*, *My*).

When the axial filament of the stalk is completely contracted, it looks like a tightly wound spiral spring, and all degrees of contraction can be observed between this condition and a nearly straight rod during the frequent contraction and expansion. When a contraction of the axial filament occurs, the myonemes in the wall of the bell usually also contract, and this brings about a contraction of the flaring peristome and the disc of the cell body. As a result, the bell-shape of the body is temporarily modified and becomes almost spherical.

Cilia. The cilia of Vorticella in the attached, or sessile, animals do not form a uniform coating over the outer surface as in Paramecium, but are restricted to the edges of the peristome and epistome, and to the vestibular space. The chief function of the cilia in Vorticella is to create a

water current which will sweep food particles into the vestibule and thence through the mouth into the gullet (W. f. 16, D, *a Sp*).

The discussion of Vorticella, so far, has been confined to the attached, or sessile, animals. But as a result either of unfavorable environmental conditions or of cell division, free-swimming animals, without stalks, may be found occasionally. In such cases an additional band of cilia specialized for locomotion is developed. This band encircles the body near where the stalk is normally attached, and the stalkless animal is able to swim freely through the water. This is a temporary condition, however, and when a suitable environment is found, the animal settles down and a new stalk is developed.

B. Life Processes of Vorticella

1. *Nutrition*

The nutrition of Vorticella is holozoic and very similar to that of Paramecium. The food particles, consisting largely of Bacteria which are swept into the vestibule and through the mouth, are collected at the base of the gullet in a gastric vacuole. As in Paramecium, there is a definite cyclosis of the endoplasm, as the result of which the gastric vacuoles are carried along in a regular path through the body. The indigestible refuse is egested through a definite anal spot which also opens into the vestibule. Carmine particles can be used with Vorticella just as with Paramecium to show various features of the process.

The excretion of liquid and gaseous wastes, resulting from the continual breaking down of the living matter, is also similar to Paramecium. There is a single large contractile vacuole which expels the liquid wastes to the exterior through an opening into the vestibule, and respiration occurs over the entire surface of the cell body.

2. *Reproduction*

In Vorticella, asexual reproduction by division takes place very frequently if conditions are favorable. Three or four divisions a day are not uncommon, so that, from a single animal, sixteen or even more typical individuals may arise within twenty-four hours. In dividing, the micronucleus is first to act, then the macronucleus, and finally the cell body. The splitting of the cell body begins first in the region of the peristome and proceeds toward the apex of the bell where the stalk is attached. For a short time after the division has occurred, two small, but complete, individuals may be attached to a single stalk. Shortly afterwards, however, one animal develops a temporary band of locomotor cilia, as mentioned above, and breaks away from the stalk as a free-swimming individual. It soon settles down, develops a new stalk, and, after a few hours or more when it has grown to a certain size, may reproduce again.

CONJUGATION. The process of conjugation in Vorticella is somewhat different from that already noted in Paramecium, in which two individuals of the same size (ISOGAMOUS) fuse temporarily for the purpose of interchanging nuclear material, and then separate when this has been accomplished. In Vorticella there is a permanent fusion of a small, specialized free-swimming individual, the 'MICROGAMETE,' with a normal attached individual, the 'MACROGAMETE.' This process is known as ANISOGAMOUS conjugation. The main features of the process of conjugation in Vorticella may now be outlined.

(1) The female macrogamete is, to all appearances, a typical Vorticella.

(2) The male microgamete is a small atypical cell without a stalk, and otherwise showing considerable divergence. It is formed by the rapid division of an apparently typical Vorticella into first two, and then into four, small equal-sized cells, all of which quickly separate and swim away to seek a macrogamete.

(3) When a microgamete comes into contact with a macrogamete, it fuses with it permanently. The place of fusion is generally on the side of the macrogamete near where the stalk is attached. The body of the microgamete is entirely absorbed, after a time, into the macrogamete, and a fusion of the micronuclear material of the microgamete and macrogamete also occurs to form a synkaryon.

(4) The essential features of the nuclear changes in the conjugation of Vorticella agree with those of Paramecium, and it is not necessary to do more than emphasize the main fact that, as a result of the conjugation, a new nuclear apparatus is built up in the macrogamete from the synkaryon, after which the individual begins another period of reproduction by division.

VII. BACTERIA [1]

In the preceding sections the structure and life processes of certain animals and green plants have been considered. It is next in order to consider a noteworthy series of organisms, the colorless plants, which fundamentally affect, and are vitally connected with, the life processes of all other living organisms. The colorless plants, or Fungi, as they are technically termed, all lack chlorophyll, and, typically, are dependent for their nutrition upon complex foodstuffs. Furthermore, the food must always be in a soluble form, so that it will pass through the cell wall. If the particular colorless plant secures its nourishment from solutions containing decaying organic material, it is said to be SAPROPHYTIC. If, on the other hand, as is frequently the case, the soluble food material is obtained from, and at the expense of, a living organism, that particular colorless plant is said to be PARASITIC.

The Fungi include such plants as the Bacteria, Yeast, Molds, Mildews, Mushrooms, etc. Their structure is usually of a simple and primitive type, particularly in the unicellular forms like the Bacteria and Yeast. A similar simplicity of structure is found in certain of the Algae, as noted in the previous study of Pleurococcus. There is a close structural relationship between the Algae and Fungi, and they are grouped together to form the lowest Phylum in the Plant Kingdom, namely, the Thallophyta (W. p. 413). The thallus plants usually have no differentiation into stem, leaves, or roots.

Although the Bacteria are commonly classified as belonging to the Fungi, their relationship to other members of this

[1] Woodruff, pp. 44–53, 309, 333.

group is by no means clear. The fact is their structure is so primitive that their exact relationships have not been determined. Notwithstanding their low type of organization, they must be regarded as a very successful group of organisms, for they are adapted to all sorts of conditions and increase with extreme rapidity. They are practically omnipresent in the air, in dust, in both fresh and salt water, and even in our own bodies.

A. Structure of the Bacteria

There are some 1400 known species of Bacteria, but, from a morphological standpoint, the single cells of all these species, although there are many gradations, can be placed in one of the following three groups: (1) the spherical COCCI (singular COCCUS); (2) the rod-like BACILLI (singular BACILLUS), and (3) the more or less spiral forms, SPIRILLA (singular SPIRILLUM). Bacteria are all microscopic in size. There are some species of Bacteria which are so small that they cannot be seen even under the highest powers of the microscope. The average diameter of the cocci type is stated to be about 1 micron (.001 of a millimeter or about $\frac{1}{25000}$ of an inch), and this measurement is also approximately correct for the average short diameter of the bacilli and spirilla forms (W. f. 13).

Apparently the cell structure of all types of Bacteria is very simple, consisting only of the cell wall and cytoplasm. A definite nucleus is not present, but it is possible in some forms to demonstrate the presence of nuclear material. The cell wall of the Bacteria is generally of a protein, rather than of a cellulose, character. In that respect it resembles the wall of an animal cell rather than the wall of a plant cell. The cell walls, in general, are double, and consist of an inner, more rigid layer and an outer, less rigid layer; the latter in many species may become somewhat deliquescent and sticky, thus causing the cells to adhere in groups of various shapes and sizes. The Bacteria, which normally

adhere to form definite cell groups, are frequently named according to the shape of the group. A discussion of this phenomenon is given below (p. 47). There are no openings in the cell wall, so that all materials must pass directly through this membrane, presumably governed by the laws of diffusion. In certain of the Bacteria definite flagella are present for use in locomotion (W. f. 13, *2*, *3*).

In addition to the simple types of Bacteria, as just described, there is a group of so-called Higher Bacteria, or TRICHOBACTERIA, in which a number of cells become attached, and thus form definite filaments. Sometimes these filaments show a true branching. The attached cells in a filament, although capable of independent existence, are slightly differentiated. A rather common example of the Trichobacteria is the Sulphur Bacteria, BEGGIATOA. In this form unbranched filaments, consisting of flat cells, are present. The cytoplasm of these cells contains sulphur granules (W. f. 158).

B. Life Processes of the Bacteria

1. *Nutrition*

Lacking chlorophyll, the Bacteria cannot manufacture food photosynthetically, and are, typically, dependent upon some sort of complex food material. But various species of Bacteria exhibit the utmost variety with regard to their food materials, which range from the very simple to the very complex. The food must, however, be in a soluble form, so that it can pass through the cell wall. This type, as noted above, is termed saprophytic nutrition. In securing food the Bacteria have the ability to secrete certain digestive ferments, or enzymes, into their immediate environment, and thus the solid food materials there present are rendered soluble and capable of being absorbed through the cell walls. This is what happens when vegetable or animal matter decays.

Bacteria, as well as all other living organisms, must have

oxygen in order to carry on certain oxidative processes which are fundamental in the life processes of all living organisms. Some types of Bacteria, known as the AËROBES, secure this oxygen directly from the air. Such forms cannot survive in an environment which lacks free oxygen. Another type, known as the ANAËROBES, secure the necessary oxygen as a result of breaking down complex food compounds. *Bacillus tetani*, which causes lockjaw, is an anaërobe (W. p. 311).

In order to bring the nutrition of certain representative Bacteria clearly to mind it may be well to divide them into a number of classes and note the environment and their effect upon it.

BACTERIA OF DECAY. It is a matter of common observation that dead matter, whether from a plant or animal, decays. Specifically, decay results in a breaking down of the complex materials, present in plants and animals, into the simpler compounds — carbon dioxide, water, nitrogenous and other mineral substances — which can again be utilized by green plants to build up foods photosynthetically. In general, it can be stated that decay is due to the action of various kinds of Bacteria, and although in many cases it causes great harm and loss, yet, fundamentally, the process is of the greatest value. If bacterial action were to stop and thus bring about a cessation of decay, the earth very soon would be filled with dead plant and animal material. Thus an enormous amount of valuable materials, which must be utilized by living organisms if life is to continue, would be unavailable.

A very common example of this type of Bacteria is the Hay Bacillus (*Bacillus subtilis*) which brings about decay in hay infusions. If a few wisps of hay are placed in a container and water added, it will very soon begin to decay. The decay is due in large part to the action of the Hay Bacilli which were present either in the water or as spores on the hay. Many other kinds of Bacteria may also be present in the very favorable environment which such an infusion

affords for bacterial life. The decay is caused by the chemical action of the enzymes secreted by the Bacteria, and, as stated above, always results in breaking down the proteins and other complex compounds into simpler substances.

Another common example of decay Bacteria is *Bacillus vulgaris*, which brings about the putrefaction or decay of animal proteins as, for example, in meat. The process of decay, in this case, causes the formation of very disagreeable gases which result from the destruction of the animal proteins. The final result is the transformation of the complex proteins of the meat into the simpler compounds of which they were originally built up.

Nitrogen-fixing Bacteria. Bacteria of this type live in the soil. They form nodules which are present on the roots of leguminous plants, such as Clover, Peas, and Beans. They are of great value in agriculture, for they enrich the soil so that more abundant crops can be raised. The enrichment of the soil is due to the ability of these forms to capture nitrogen from the air and 'fix it' in the form of nitrates. The nitrates are then utilized by the green plants in building up the proteins.

It should be stated that there are also some types of soil-living Bacteria, known as the denitrifying bacteria, which carry out a reverse process and break down the nitrates in the soil and thus release the free nitrogen. They deplete, rather than enrich, the soil and are consequently a detriment to green plant life.

It is also of great interest to know that at least one group of soil-living Bacteria has been found which are able apparently to unite carbon dioxide and water, and thus form their own food. The energy to do this is derived, not from sunlight, as in the green plants, but from certain oxidative processes. This process is known as chemosynthesis.

Fermentation Bacteria. This type of Bacteria is concerned with the souring of certain substances, but not with the formation of alcohol; the latter being chiefly due

to the action of another unicellular fungus plant, known as Yeast, which will be considered in the following chapter. An example of the action of the Fermentation Bacteria is to be seen in the manufacture of vinegar. During the first stage of vinegar formation the cider is acted upon by the Yeast cells, and the sugar present in solution in the cider is changed into alcohol and carbon dioxide. The alcohol is then acted upon by *Bacterium aceti* in the presence of free oxygen and changed into acetic acid and water. The weak solution of acetic acid in water, together with certain aromatic substances present in the original cider, constitutes commercial vinegar.

There are other Bacteria known, which are able to change the acetic acid in their environment into carbon dioxide and water. The latter constitute the simple substances which green plants make use of in photosynthesis to form sugar. In other words, the processes just described constitute one of the carbon cycles in nature (W. f. 15 A, B).

There are numerous other forms of Fermentation Bacteria which are of commercial importance, such as *Bacterium lactis acidi*, which causes milk to sour by changing the milk sugar to lactic acid. Others are necessary in cheese manufacture, and still others aid in the ripening of tobacco, etc.

Pathogenic Bacteria. Many of the worst diseases that affect both plants and animals are caused by an invasion or, as it is termed, infection of parasitic Bacteria. Plant diseases, such as certain Blights, Galls, and Rots, result from the action of Bacteria. In Man and domestic animals such diseases as Tuberculosis, Diphtheria, Anthrax, Pneumonia, Gonorrhoea, Septicaemia, Erysipelas, Typhoid Fever, Tetanus, Cholera, as well as a great many others, are due to Bacteria.

The ravages of these diseases are due in some cases, for example in Tuberculosis, to the actual invasion and destruction of the living tissues by the bacterial cells. In other

diseases the harm is caused by certain poisonous substances, known as TOXINS, which are given off into the body of the host. The toxins are formed by the Bacteria as by-products of their own metabolism (W. pp. 338–339).

2. *Reproduction*

The process of reproduction in Bacteria is extremely simple and also extremely rapid. So far as known the process is always an asexual one in which the cells divide by transverse fission into equal halves. The daughter cells, if the environment is favorable, attain full size and are ready to divide again within 20 or 30 minutes, so that it has been estimated that the descendants of a single individual of the Hay Bacillus, for example, would number 281,500,000,000 in 48 hours. At this rate, if the environment were to continue favorable, it would only be a comparatively short time until the progeny of a single Bacterium would completely fill the known universe.

Favorable environmental conditions are only temporary, however, and soon the rapid multiplication is obliged to stop. Under such conditions some of the Bacteria form thick-walled spores. Life processes in these spores are at a very low point. In this dormant condition there is no absorption of food, and, owing to the thick wall, the cells are able to withstand drying and great extremes of temperature. It is in this dormant spore condition that Bacteria are present in the air and dust, and when, perchance, a suitable environment is found, the thick wall of the spore soon dissolves and an active existence is begun with very little delay (W. f. 160).

CELL GROUPING. In some species of Bacteria the cells completely separate at the time of division. A single cell of this type is generally referred to as a Micrococcus or a Microbacillus. In other Bacteria, the cells, which may be either cocci or bacilli, remain attached in pairs, and these are known as Diplococci or Diplobacilli; or the cells may be

attached in groups of four, and these are known as Tetracocci. Frequently long chains of cells are formed, and these are known as Streptococci or Streptobacilli. In some of the cocci a considerable number of cells may adhere to form a group of cells shaped more or less like a bunch of grapes, and such groups are referred to as Staphylococci (W. f. 13).

Some forms of Bacteria secrete an abundant gelatinous material in which the cells remain embedded. There is soon built up in this way a common gelatinous mass, known as zoögloea. This term indicates an animal origin, and is a relic of the days when the Bacteria were regarded as animals. Coenogloea is a preferable term.

C. The Cultivation and Identification of Bacteria

It is doubtful if there is any science that has ever made, in the same length of time, as great progress as has Bacteriology. Starting with the basic work of Pasteur and Koch, our knowledge of the Bacteria has grown by leaps and bounds. The foundation for all this advance in our knowledge of the Bacteria was the discovery of methods by which pure cultures of these organisms could be grown and studied, and their mass-reactions observed. As has been noted, a single Bacteria cell is generally so tiny that the microscope reveals very little difference in structure between the different species. It was therefore necessary, in order to identify them, that methods be devised whereby Bacteria could be grown in pure cultures and the mass-reactions of enormous numbers of cells noted.

It was first necessary to secure a culture medium which could be sterilized and thus freed from all other forms, and which would also offer a favorable environment for the growth of the Bacteria cells. It was found, for example, that agar, a plant material, could be boiled, together with a certain proportion of beef broth, and the sterile mixture poured while hot into test tubes or into flat glass dishes. As the mixture

cooled it solidified like gelatine. Many kinds of Bacteria, when introduced into this culture medium, will multiply very rapidly. Thus it became possible to inoculate a sterile culture medium in a test tube or other container with the particular type of Bacteria which it was desired to identify or to study in various other ways. After inoculation such a culture can be kept at a suitable temperature for a day or so until an enormous number of Bacteria have developed. These can then be studied both by their reaction and appearance as a mass, and also as isolated individuals.

Such cultures show that the various types of Bacteria have specific mass-effects on the agar medium in which they are growing; some forms will produce certain colors; others, definite types of growth; others, liquefy the medium, etc. It is, therefore, possible by a study of the various characters produced by the mass-reaction to identify the various Bacteria. If, for example, a physician is called to attend a patient, and from the general appearance of the throat suspects diphtheria, he touches the infected parts with a bit of sterile cotton on a swab. The swab is then carefully placed in a sterile tube. Later, in the laboratory, the swab is rubbed across the surface of a sterile agar culture medium in a dish. The infected culture medium is then kept in an incubator at the correct temperature for a certain number of hours, so that great numbers of the Bacteria obtained from the throat swab will have time to develop. Observations can then be made, and it will be possible to tell from the reactions and appearance of the culture medium, due to the mass-action of the Bacteria, whether the patient has diphtheria or not.

VIII. YEAST [1]

The Yeasts, like the Bacteria, are widely distributed unicellular fungus plants with very simple structural features. There are numerous species of Yeast known, some of which have become 'domesticated,' and as such can be purchased in the form of dried or compressed Yeast cakes. Such a cake contains an enormous number of Yeast cells, in a more or less inactive condition, mixed with a certain amount of flour obtained from various cereals. In such a condition the Yeast cells retain their vitality for awhile, and become active when given the proper environmental conditions.

The wild strains of Yeast are almost omnipresent, as can be shown by exposing fruit juice for a time. Very shortly the juice will be found to have fermented, and, when examined microscopically, to contain great numbers of Yeast cells. The introduction of the Yeast to the fruit juice in such a case has occurred by means of the inactive spores which are present in various places.

The action of all varieties of Yeast cells is fundamentally the same. They are able, by means of a secreted enzyme, to act on the sugar in a solution and change it into alcohol and carbon dioxide. This is known as alcoholic fermentation. Moreover, the different varieties of Yeast show marked preferences for a particular environment. Yeasts also have certain physiological peculiarities, such as the particular flavor they impart to a liquid, the percentage of alcohol they can form, etc., which makes them adapted for definite uses.

A. Structure of the Yeast Cells

A Yeast plant consists of a microscopic, egg-shaped cell, with a thin cellulose cell wall which encloses the cytoplasm.

[1] Woodruff, 309–310.

The cytoplasm of a young cell appears quite homogeneous. In the older cells various kinds of particles can generally be observed in the cytoplasm. There is also a comparatively large cell vacuole, near the center of the cell (W. f. 159, *A*). The nucleus of a Yeast cell is not well-developed. It lacks a definite nuclear membrane and really consists of a small mass of very fine chromatin granules toward one end of the cell, which can only be demonstrated in material which has been treated with special staining methods (W. f. 159, *B*).

B. Life Processes of the Yeast Cells

1. *Nutrition*

A Yeast cell must obtain its food in soluble form from complex compounds which have been built up by the green plants. The nutrition of Yeast, therefore, like that of the Fungi in general, is saprophytic. Fruit juices or the solutions obtained by soaking sprouted grain in water afford the most favorable environment for Yeast. Such solutions contain the substances which are essential for the nutrition of Yeast.

Yeast cannot live on a sugar solution alone. It must, in order to repair the continual wastes of its own protoplasm, have a more complex compound in which nitrogen is present. Yeast can, however, obtain the necessary nitrogen from a solution containing ammonium tartrate which is a simpler compound than even the simplest of the proteins. Green plants, as already noted, can take carbon dioxide, water, and mineral salts and build up their foods. Yeast, if necessary, can utilize ammonium tartrate. Animals, however, require more complex nitrogen compounds as part of their food stuffs. It is clear, therefore, that the Yeast cell, in its nitrogen nutrition, occupies an intermediate position between green plants and animals.

For the excretion of the waste products of metabolism, Yeast has no specialized structures, and the entire process is carried on by diffusion through the permeable cell wall.

ALCOHOLIC FERMENTATION. One of the characteristic things about Saprophytes is their ability to give off into the surrounding environment certain specific chemical agents, known either as ENZYMES or FERMENTS, which are able to cause definite chemical reactions necessary for various metabolic activities. Thus it is with the Yeast cells. The cytoplasm manufactures an enzyme, known as ZYMASE, which, when given off into a sugar solution, causes the disintegration of the sugar molecule and the formation from it of alcohol and carbon dioxide. By means of this process the Yeast secures energy for metabolism. Fundamentally, the process may be regarded as constituting the respiration of the Yeast, and the carbon dioxide and alcohol as the by-products resulting therefrom. While there is considerable variation as to the amount of alcohol which may be formed in a liquid without causing harm to the Yeast cells, it has been shown that the maximum amount, for any species, is about 16 per cent.

2. *Reproduction*

The reproduction of most species of Yeast is entirely asexual. It takes place either by budding or by spore formation. The latter method is adapted for tiding the organism over unfavorable environmental conditions.

In reproduction by budding, which is a very common process in an active culture of Yeast, the cellulose wall of the cell is pushed out at one pole by the cytoplasm, and a little knob, or bud, forms. The bud rapidly increases in size and is soon almost as large as the mother cell. At this stage the bud may break away and begin an independent existence, or it may remain attached and form other buds. In the latter cases a colony, consisting of a considerable number of attached cells, is soon formed (W. f. 159, *C*, *D*).

Reproduction by spore formation generally occurs when the environmental conditions of the Yeast cells, *i.e.*, the solution in which they are present, becomes unsuited for their

active vegetation. The unfavorable condition may arise by an evaporation of the fluid, the exhaustion of the food supply, or by the presence of too high a percentage of alcohol.

In spore formation, the cytoplasm in the Yeast cells divides into two, three, or four definite round bodies, the SPORES which remain enclosed in a heavy wall. Spore formation is purely an asexual process. In this condition the Yeast cell is dormant and can withstand drying, extreme temperature, etc., which would kill active vegetative cells. When the cells again find a suitable environment, the spores emerge from the enclosing wall and at once begin active operations.

3. *Economic Importance*

Yeast is employed in bread-making to raise the dough. In such cases the Yeast is added to a mixture of flour and water, which contains a little sugar solution. The enzyme secreted by the Yeast cells acts on the sugar, forming a small amount of alcohol together with carbon dioxide gas. The latter, passing through the bread, leavens it and makes it porous. The spaces occupied by the gas remain permanently in the bread when baked. The small amount of alcohol passes off during the baking.

In the making of wine and cider the enzymes of the Yeast cells break down the sugar present in the fruit juices, and varying amounts of alcohol are thus formed. In brewing, the Yeast is added to a sugar-containing solution, made by soaking sprouted, crushed grain in water. The sprouting of the grain converts a certain amount of the starch present in the seeds into sugar, and the Yeast acting on this sugar forms alcohol from it.

IX. BREAD MOLD

The common Bread Mold may be made use of as a typical example of an important group of Fungi which possess a comparatively large and somewhat differentiated filamentous plant body as distinguished from the tiny, undifferentiated bodies of the Bacteria and the Yeasts. The Bread Mold and many other related species are associated with the decay of numerous food products. The decay, just as in other Fungi, results from the action of the secreted enzymes. These render the organic materials, with which they come into contact, soluble, in which condition these saprophytic organisms can secure and utilize them as nourishment. Here again in the Molds the ubiquity of these fungus forms is to be noted. As a rule it is only necessary to expose a piece of bread to the air for a little while and then keep it moist in order to secure, in a few days, a plentiful supply of the plant. The spores of the Mold, present in the dust and air, fall on the bread, where they very soon develop into actively growing plants. The Bread Mold will also grow readily on various other substances, such as fruit and vegetables in storage.

A. Structure of the Bread Mold

The surface of the bread, or other material, on which this Mold is growing, becomes covered in a few days with a delicate, white filamentous growth. Examined microscopically, the Mold is found to be composed of a dense network of fine, white filaments. These are known as hyphae (singular hypha) (W. f. 14). Three distinct types of hyphae may be seen. There are, first, the relatively thick hyphae which

run on the surface and also ramify through the substance of the bread, and thus serve to spread the organism throughout the material. These are known as the STOLONIFEROUS HYPHAE, or simply STOLONS. Attached to these, at more or less regular intervals, are two other types of hyphae: the groups of short, root-like hyphae which penetrate deeply into the bread, and, finally, single erect hyphae (SPORANGIOPHORES) which project up from the surface of the bread. The free ends of the erect sporangiophores enlarge to form spore-cases, or SPORANGIA (singular SPORANGIUM), in which the specialized, asexual, reproductive bodies, or SPORES, form. The hyphae are not divided into cells, but, nevertheless, contain numerous nuclei.

B. Life Processes of the Bread Mold

1. *Nutrition*

The Bread Mold is a saprophyte and, therefore, takes in the necessary foods by diffusion through the cell wall. The hyphae, which are in contact with the bread, secrete enzymes. These act on the solid substance of the bread and change it into a soluble material which can pass through the walls of the plant. This absorbed liquid food is assimilated by the protoplasm of the Bread Mold, the growth of the plant results, and so the infected piece of bread is soon permeated with the hyphae.

2. *Reproduction*

Asexual Reproduction. Very shortly after the Bread Mold begins to grow in a new environment, the sporangiophores, each having a sporangium at its tip, begin to form. In the first stage of the formation of a sporangium there is just a slight enlargement to be noted at the tip of the hypha. This region is plentifully supplied with the absorbed food material and, as a result, it enlarges very rapidly and soon

forms a comparatively large, round, brown knob, the mature sporangium (W. f. 14, B, A).

The dark color of the older growths of Bread Mold is due to the presence of great numbers of tiny, unicellular spores which form inside the sporangia. The color of the spores deepens as they get older, so that old cultures of Bread Mold are almost black. When the spores are ripe, the walls of the sporangia break open, and great numbers of the enclosed spores, which are very resistant to all sorts of unfavorable environmental conditions, are set free. They become widely distributed and develop rapidly into the mature plant whenever a suitable environment is found.

SEXUAL REPRODUCTION. The Bread Mold also reproduces by a primitive type of sexual reproduction. This method somewhat resembles that found in certain of the Green Algae, a fact which is regarded as evidence of a distant relationship between these two groups of plants.

In the sexual reproduction of the Bread Mold, two of the root-like hyphae come into contact near the tips and fuse. A portion of each hypha, lying close to the fused tips, becomes differentiated to form a characteristic structure, known as a ZYGOSPORE, but which is a ZYGOTE (W. p. 455). The zygospore enlarges, and a rough, brown outer covering forms. When it is mature, the remainder of the two hyphae degenerate. In this type of reproduction one of the hyphae may be regarded as the male element, and the other as the female element, even though their structure is the same. Experimental evidence shows apparently that the female strain is more vigorous than the male.

C. OTHER FUNGI OF INTEREST

OTHER MOLDS. There are many other common species of Molds which superficially resemble the Bread Mold. These include various species of Penicillium which find a suitable environment in many food substances, such as

canned and fresh fruits and, frequently, apples in storage. The distinctive flavor of Roquefort and Camembert cheese is due to the action of two species of Penicillium. Aspergillus is another filamentous Mold, the several species of which are very common, and destructive to foods and other materials.

Pathogenic Fungi. The action of Bacteria in producing various diseases in plants and animals has already been noted. There are a great number of other fungus forms which have the same faculty. Such plant diseases as Potato Rot, Downy Mildew of Grapes, Brown Rot of various fruits, Chestnut Blight, Pine Tree Blister, the Rusts and Smuts of various cereals are all due to fungus growths. The annual loss from these diseases is appalling. Also, there are a number of diseases both of Man and other animals which are known to be due to an invasion of certain Fungi other than Bacteria.

Mushrooms and Toadstools. The highest group of the Fungi, known as the Basidiomycetes, includes the Mushroom and Toadstools as well as a number of very destructive parasitic forms, such as the Rusts and Smuts, which cause enormous damage to the cereal crops. Some 10,000 species of Mushrooms and Toadstools are known; some of them are edible, while many others are very poisonous. The selection of the edible species should be left entirely to experts, as there are no structural features by which they can be readily distinguished. In these types of Fungi, the mycelium forms a filamentous growth in soil containing decaying organic materials, and thus the plants secure their nourishment. The portion of the plant above ground is known as the sporophore and consists of a short stalk, or stipe, bearing an umbrella-shaped enlargement, the pileus. Underneath the pileus are the spore-bearing 'gills.'

The Lichens. The Lichens consist of some 4000 species of plants which are of particular interest, in that the plant body consists not of a Fungus alone, but of a Fungus living

in close symbiotic relationship with an Alga. The various Lichens show considerable differences in their appearance, but a particular species is constant; in other words, a certain Lichen always consists of the same Fungus and Alga together (W. f. 179).

X. VOLVOX [1]

Volvox is a colonial, fresh-water organism, the body of which consists of a great number of independent flagellated, cells. These cells are quite similar to Euglena in structure, and like the latter have the holophytic type of nutrition. The presence of chlorophyll, just as in Euglena, makes the exact classification of this organism a doubtful question. It is either placed in the phylum Protozoa with the other flagellated animals or with the Algae as a primitive plant form.

Our main point of interest, however, in connection with Volvox lies in the fact that each individual consists of a great number of cellular units bound together to form a colony. These body, or somatic, cells of Volvox show an entire lack of specialization except for purposes of reproduction. In other words, each one is a balanced structural and physiological unit capable of carrying on the necessary life processes independently of the other cells of the colony.

In the true multicellular organisms, whether plant or animal, there is an ever increasing amount of cell specialization as we ascend in the scale of development. Along with this has come a division of labor between the cells, so that in a typical Metazoön, the cells have become both structurally and functionally specialized to such an extent that they are capable of performing only certain of the life processes which contribute to the welfare of the organism as a whole. Thus, in these higher forms, the functions of nutrition, movement, coördination, and numerous others are carried out by certain groups of cells which are differentiated and adapted for their own particular field.

[1] Woodruff, pp. 54–60.

A. Structure of Volvox

Volvox is large enough to be seen with the naked eye. It may be described as a small, green, hollow sphere, the wall of which is composed of some ten or twelve thousand microscopic, flagellated, chlorophyll-bearing cells, together with a transparent, gelatinous, intercellular material, the MATRIX. The latter is formed as a common secretion and serves as a cement to hold the cells of the colony together (W. f. 18, *A*).

The cells in a mature Volvox colony are of two kinds, the somatic, or body, cells and the specialized reproductive cells. There are many more somatic than reproductive cells. Each somatic cell may be compared in its general plan of organization with a single Euglena, and it carries on the life processes in the same way. However, it should be noted that each Volvox cell possesses two flagella instead of one, as in Euglena, and also that from each Volvox cell several protoplasmic strands are given off which run through the matrix and connect with similar strands from the surrounding cells. Thus there is an anatomical and physiological continuity between all the cells of the colony (W. f. 18, B).

Each of these bi-flagellated cells of Volvox is made up of ectoplasm and endoplasm, and contains a contractile vacuole, nucleus, stigma, and numerous chloroplastids. The cells are similar in structure to various other kinds of independent, flagellated Protozoa which never form colonies.

B. Life Processes of Volvox

1. *Metabolic Activities*

The previous study of Pleurococcus (p. 18) makes it unnecessary to describe in detail the holophytic nutrition of the somatic cells of Volvox. It should be emphasized, however, that these somatic cells of Volvox are responsible not alone for supplying food for their own individual needs,

but also for certain needs of the colony as a whole; notably the formation and upkeep of the intercellular matrix and the nourishment of the reproductive cells of the colony, both of which are to be regarded as the property of the entire colony. On the contrary the somatic cells have lost the power of reproduction, so that, instead of being completely balanced cells, as in Amoeba or Euglena, capable of performing all of the life processes, they have become at least temporarily specialized for the nutritive functions of the colony.

2. *Reproduction*

The Volvox colonies reproduce either asexually or sexually. In both cases the process takes place by means of specialized cells which have become physiologically and structurally differentiated for the purpose of reproduction. Such cells lack flagella and, as will be seen, are otherwise structurally modified (W. f. 18, *B*, *rp*).

In asexual reproduction, certain large cells without flagella (PARTHENOGONIDIA) begin to divide. The cells thus formed remain attached to each other, and very soon, as a result, a new colony is formed. During the early stages of formation, the new group occupies a place in the wall of the original mother colony, but, as more and more cells are formed, it later moves from the wall into the central cavity of the mother colony, where, together with several other similar groups, it continues to grow by cell division until, finally, the wall of the parent colony breaks down, thus permitting the new asexually formed colonies to escape and to take up their independent existence. They have the same structure as the mother colony except that, for a time, they are not composed of so large a number of cells.

In the sexual reproduction of Volvox a considerable number of large reproductive cells, without flagella, are formed among the normal somatic cells. These reproductive cells become specialized into the male elements (SPERM) and the

female elements (EGGS). The sperm of Volvox are formed by the division of specialized reproductive cells. As a result a flat, plate-like body, composed approximately of 128 sperm, is formed from a single male reproductive cell. When mature, these male elements separate and escape into the water. As is typically the condition in all organisms, the sperm of Volvox are free-swimming, and thus they are enabled to come into contact with the egg, which is inactive (W. f. 18, *A* ♂).

In the formation of the EGGS, the female reproductive cells enlarge, but do not divide, and so each forms a large cell, with which a sperm cell fuses permanently, thus bringing about a permanent union of the nuclear material of the two gametes. This is known as FERTILIZATION. In Volvox, the sexual reproduction generally occurs in the fall, and the ZYGOTES, which are formed from the fusion of the male and female elements, secrete a protective covering which enables them to withstand the lower temperatures of the winter season. In the following spring, when the water warms up, the zygote begins to divide and soon develops into a typical Volvox colony. It appears, therefore, that the sexual method of reproduction, with the consequent zygote formation, enables the organism to survive unfavorable environmental conditions (W. f. 115, *B*).

XI. SPIROGYRA

Spirogyra is a filamentous green plant which is frequently found floating on the surface of stagnant, fresh-water ponds, and, therefore, is commonly known as a Pond Scum. It belongs, as do also Pleurococcus and Sphaerella, to the Algae, and is one of the simple multicellular forms of plant life. The individual cells constituting the plant body of Spirogyra do not show any differentiation either in structure or function except in reproduction.

Spirogyra is frequently associated in its habitat with a number of other closely related species which have the same general structure, but which lack the beautiful long, spiral chloroplastids, one or more of which are characteristic of the various species of Spirogyra. The simple type of multicellular plant body, the remarkable chloroplastids, the primitive type of reproduction, together with its wide distribution, make Spirogyra one of the forms most commonly studied in biological courses.

A. Structure of Spirogyra

Spirogyra consists of a number of comparatively long, tubular cells attached end to end in a linear series to form a fine, hair-like filament (W. f. 22). The cells, although attached, are independent units, each carrying on the essential life processes. Each cell is entirely enclosed by a quite rigid, cellulose cell wall which is formed by the cytoplasm of the cell. There are no openings in the cell wall. It is, however, permeable to certain substances, and all interchange of gases and fluids between the cell and its environment takes place through it. The cell wall is covered externally by a thin gelatinous secretion (W. f. 22, *a*). The cytoplasm forms a rather thin layer, lying just below the cell wall. A number

of cytoplasmic strands are given off from this layer, which run from one side of the cell through the large central cell vacuole and attach to the cytoplasmic layer on the opposite side (W. f. 22, *b*). The nucleus lies near the center of the cell surrounded by a thin layer of cytoplasm and suspended by the cytoplasmic strands (W. f. 22, *c*). The long, spiral, ribbon-like chloroplastids are also embedded in the cytoplasm which lines the cell wall. Each chloroplastid contains a number of distinct spherical bodies, the PYRENOIDS, which serve as centers for the formation and storage of certain of the food materials (W. f. 22, *d*, *e*). The cell vacuole, as is generally the case in plant cells, occupies a large portion of the cell and is filled with a clear fluid, the CELL SAP, which contains various substances in solution necessary for the life of the cell (W. f. 22, *f*).

B. Life Processes of Spirogyra

1. *Nutrition*

In the previous study of the more primitive green plant, Pleurococcus, the holophytic type of nutrition was described. Since this fundamental process is essentially the same in Spirogyra and, for that matter, in the chlorophyll-bearing cells of all green plants, it is not necessary to consider it again. However, attention should be called to a feature of the chloroplastids of Spirogyra which was not to be observed in those of Pleurococcus, namely, the presence of specialized structures, the pyrenoids, which are centers for starch formation and storage. The sugar resulting from photosynthetic action is transformed by these bodies into starch, in which condition it is stored for later use.

2. *Reproduction*

Spirogyra reproduces asexually and also by a primitive sexual method. In the case of asexual reproduction, which

occurs with considerable frequency under suitable environmental conditions, the cell divides transversely into two cells, each of which when first formed is one-half the length of a normal cell. The actual division of the cell wall and cytoplasm is preceded by a division of the nucleus. The cells formed asexually by fission remain attached and soon grow to normal size, thus increasing the length of the filament.

In sexual reproduction, the cytoplasmic and nuclear constituents of a cell in one filament fuse with those of a cell from another filament. The first step in this process occurs when two filaments of Spirogyra come to lie in a parallel position and quite close to each other. Projections then begin to form from the walls of the apposed cells. These projections grow larger, and those from one cell soon become fused with those of a cell of the other filament; the end result being the formation of an open passageway between the two cells. Similar passageways may be formed between many of the cells of the two filaments. The protoplasmic contents, or PROTOPLAST, of each of the connected cells now breaks down, loses its characteristic structure, and the protoplast of one cell moves out of the cell wall, through the open passageway, and into the other cell, where it fuses with the other protoplast to form an oval-shaped body, the zygote, which, owing to a secreted protective covering, is able to withstand unfavorable environmental conditions. In this simple type of sexual reproduction, the active migratory protoplast is regarded as a primitive type of male element, or sperm, and the inactive, quiescent protoplast as the female element, or egg.

XII. MOSS[1]

We are now ready to turn our attention to a group of green plants, the Mosses, which show a considerable advance in structure over those previously studied. The plants included in the phylum Bryophyta, to which the Mosses belong, are the simplest land plants. They are believed to have originated from the Algae and to be the first group of plants to leave the water and to acquire what may be termed the land habit. Along with the new environment there necessarily came various adaptive changes in their structure, which enabled them to survive on land. These structural changes were mostly concerned with protecting the plant in its new environment from a too rapid evaporation of moisture and in adapting the food-making tissues to the new conditions. Leaves, which are essentially the specialized food-manufacturing organs, are present. One feature of the Mosses, which is of particular interest in our present study, is their method of reproduction. The Mosses exhibit a process known as alternation of generations, which means that in the life cycle there are two generations, the sexual and the asexual, which alternate; the one producing the other. This process is shown in some of the higher Thallophyta. In the Mosses it becomes firmly established, and in them and in the higher plants it is of universal occurrence, although subject to great variation.

A. Structure of the Moss

Sexual Generation. The sexual generation, or gametophyte, of the Moss is what is commonly recognized as the Moss plant. It consists of a short upright stem, bearing

[1] Woodruff, pp. 100–103.

leaves and rhizoids, which in none of the Mosses grows to more than a few inches in height. The rhizoids are fine, filamentous structures which serve to attach the stem of the gametophyte to the substratum, and function, in general, as do the roots of higher plants. Their structure is different, however, and they are not regarded as true roots (W. f. 53, *a*).

The gametophyte produces the sexual organs, containing either sperm or eggs, at the tip of the upright stem which has just been described. In some species a single plant bears both male and female organs, while in other species they are borne by separate plants (W. f. 53, *f*, *h*). A microscopical examination of the sexual organs in a Moss gametophyte of the former type shows that the sperm are formed in club-shaped, multicellular organs, known as ANTHERIDIA (singular ANTHERIDIUM), several of which are generally present on each gametophyte. Each mature antheridium contains enormous numbers of the developing sperm (W. f. 53, *i*). The structure of a mature sperm cell is very unlike that of a cell from other parts of the Moss plant, and consists largely of nuclear material. The remainder of the sperm is made up of a small amount of cytoplasm which is drawn out in the form of a double, filamentous, whip-like structure. The latter has the power of rapid vibration, thereby giving the sperm cell the power of locomotion in a liquid (W. f. 53, *j*).

The egg cells are developed in slender, flask-shaped, multicellular organs, known as ARCHEGONIA (singular ARCHEGONIUM) (W. f. 53, *g*). One egg develops in the enlarged basal portion (VENTER) of each archegonium. The mature eggs of the Moss, as well as those of most organisms, retain a typical cell structure, except that they are somewhat larger. This is due to a storage of food material in the cytoplasm. The egg, unlike the sperm, has no power of movement, so that, in order for it to develop, it is necessary that a sperm cell reach, and permanently fuse with, it, thus bringing about fertilization. In order to reach the egg, the sperm must have

moisture. They can then swim about and find the opening in the tip of an archegonium, which leads directly to the egg cell lying in the venter below.

Asexual Generation. The sporophyte develops from a fertilized egg cell in an archegonium at the tip of the gametophyte, and it remains permanently attached to the gametophyte at this point (W. f. 53, *k*). Furthermore, it is dependent upon the gametophyte for the food materials necessary for its development. When fertilization has occurred, the zygote, without changing position in the archegonium, begins to divide, and as a result many cells are soon formed, which remain attached and really constitute the immature sporophyte.

The young sporophyte continues to develop by cell division and soon forms a small rod-like embryo, one end of which grows down into the tissues of the gametophyte and absorbs nourishment, while the other end projects farther and farther in the opposite direction from the tip of the gametophyte. When the sporophyte is fully developed, it consists of, first, a part, the foot, which is attached to the tissues of the gametophyte and receives nourishment from them, and, second, a long, thin stalk which supports, at the distal end, an enlarged portion, termed the capsule (W. f. 53, *b*). A mature capsule contains great numbers of tiny, brown spores which develop asexually (W. f. 53, *c*).

The spore capsule of the Moss is quite complicated in its structure. There is a lid (operculum) at its tip, which is forced off at the proper time by the swelling of a special ring of tissue (annulus). Lying below is a circle of specialized, tooth-like structures, which aid in scattering the spores. At the base of the capsule is a slightly enlarged portion, known as the apophysis, which is of significance because, in some forms of Mosses, it contains chlorophyll and aids in food-making.

After being set free from the sporangium, the spores are scattered, and those which secure suitable places germinate

(W. f. 53, *d*). Active growth begins, and soon results in the formation by cell division of a small, green, branching, filamentous structure, the PROTONEMA (W. f. 53, *e*). This is only a temporary phase in the life history of the Moss, and soon buds appear on the protonema, which develop into the erect, green, leafy gametophytes with sexual organs at their tips. This brings us back to our starting point in the life history of the Moss.

VEGETATIVE REPRODUCTION (ASEXUAL). Another type of asexual reproduction may take place in the Moss simply by vegetative growth, in which case the spores do not play any part in the process. In fact, in some Mosses which are found in arid regions the formation of the sporophyte generation rarely occurs. Presumably this is due to the fact that under such conditions it is impossible for the sperm, adapted as they are for movement in a liquid, to fertilize the eggs in the archegonia. Consequently, the spread of these species is entirely dependent upon the vegetative growth. This may take place in a number of ways, for example, by the isolation of branches by the death of the older portions of the plant, or by the irregular formation of protonemata on the leaves and stems of the gametophyte, which later become separated from the parent stalk and develop into independent gametophytes. Finally, asexual vegetative reproduction occurs in some Mosses by the development on the gametophytes of flat plates of cells, known as GEMMAE. These also become detached from the parent stalk and, falling on suitable soil, develop into independent gametophytes.

B. LIFE PROCESSES IN THE MOSS

The independent, chlorophyll-bearing gametophyte of the Moss manufactures its own food in the same way as do all green plants. The food manufactured by the leaves of the gametophyte is used not only by that generation, but is also supplied to the attached sporophyte, which, in general, entirely lacks the power of photosynthesis.

In the higher plants, there are great problems involved in the transportation of various necessary materials to the different regions of the plant, such as from the roots to the leaves, and so a highly specialized vascular tissue is present, which carries out this important function. The Moss, however, is a small plant, and a special vascular tissue is not present.

C. Related Forms of Interest

The Bryophyta in addition to the common Mosses, or Musci, include a group of more primitive types, known as the Liverworts, or Hepaticae, which are generally regarded as representing the transitional group between the more simple water-living plants and the higher land plants. A considerable variation in structure may be found among the 4000 or more species belonging to the Liverworts, but typically the plant body is a plate-like thalloid structure which grows in places where moisture is very abundant (W. p. 413–414).

Included among the True Mosses, or Bryales, are the more primitive Sphagnales which are adapted for habitats possessing a plentiful supply of moisture, such as a shallow pond or lake. In such a place they grow in great abundance and in time build up the peat bogs. The material from bogs of this type is utilized as fuel, particularly in Ireland. The Sphagnum Moss has considerable absorptive and antiseptic properties and is used to some extent in surgical dressings. It is also valuable for use as a packing material.

XIII. FERN[1]

The Ferns are an abundant and highly organized type of plant. They belong to the phylum Pteridophyta, which also includes less well-known forms of plants, such as the Horsetails and Lycopods. It is evident, from the fossil specimens which have been obtained, that the plants belonging to this phylum were larger and far more abundant in past geologic ages than at the present time (W. pp. 356–359).

The various tissues of the Ferns are more highly differentiated, and altogether they show a considerable advance in structure as compared with the Mosses. This fact is shown to particular advantage in the well-developed vascular tissue of the Ferns. It is by means of this tissue that the Ferns are able to transport the simple food materials to the leaves and the manufactured food to all parts of the plant. The development of a high type of vascular tissue in the Ferns is believed to have been an important factor in their development in that it enables them to grow to a much larger size than is possible in the Mosses. The Ferns and Flowering Plants are grouped together by some authorities as the Vascular Plants, thus separating them from the Thallophytes and the Mosses, which are Non-Vascular Plants. The plant body of the Fern shows a marked advance, in that roots, as well as stem and leaves, are present.

The phenomenon of alternation of generations in the Ferns is of universal occurrence. This process, in the common Fern, in which a great development of the sporophyte generation and a corresponding degeneration of the gametophyte generation is present, is quite different from that in the Mosses and is the forerunner of even greater changes in the

[1] Woodruff, pp. 103–106.

same direction, which are found in the Flowering Plants. The sporophyte of the Fern is no longer a dependent, parasitic structure as in the Mosses, but is a high type of independent plant. (W. f. 55)

A. Structure of the Fern

Asexual Generation. The asexual, sporophyte generation of the Fern is the one commonly recognized as the Fern plant, and in a number of species of Ferns this generation is of considerable size. It consists of the leaves, or fronds, as the leaves of the Ferns are sometimes called, which are above ground, and the underground stem, or rhizome, to which the roots and leaves are attached. The leaves, therefore, constitute what may be termed the aërial portion, and the stem and roots, the underground portion (W. f. 54, *a*).

A leaf consists of the supporting stalk, or petiole, which also attaches it to the rhizome, and a blade which is specialized for photosynthetic food manufacture. The blade is subdivided into many smaller portions, known as pinnae. In some species of Ferns the pinnae are further subdivided into leaflets, or pinnules.

The rhizome of a Fern consists of a number of differentiated tissues which are comparable in structure to those found in the stem of the Flowering Plants. There is, first, an outer protective layer of epidermal cells. Lying just within the epidermis is the region of the cortex, consisting of several layers of cells modified for support and storage. The specialized vascular tissue, which functions for the transportation of soluble materials, lies near the center of the stem in the form of vascular bundles. In the central area of the rhizome is an undifferentiated tissue, known as the pith, which serves largely as a storage tissue.

The roots of the Fern are like those found in the highest types of plants, and quite unlike the simple rhizoids of the

Moss. Their general plan of structure is much the same as in the stem. The outer epidermal cells, near the tips of the roots, are specialized for absorption, and many of them develop tiny, hair-like projections, known as ROOT HAIRS. It is through the latter that water, containing simple food materials in solution, is absorbed from the soil, taken into the roots, and then later conveyed by the vascular tissue through the stem to the leaves. The microscopical structure of the Fern is not essentially different from that of the Flowering Plants, and, consequently, a histological study of these plant tissues may be left until that higher group of plants is considered.

Turning now to a consideration of the relations shown by the sporophyte of the common Fern to the process of alternation of generations, it will be found that two types of leaves are present, first, the sterile, or FOLIAGE, leaves, and second, the fertile leaves, or SPOROPHYLLS, which bear spores on the under surface (W. f. 54, *b*). The spores are formed in characteristic, brownish-colored bodies, known as SORI (singular SORUS). Each sorus is partially covered by an outgrowth, the INDUSIUM (plural INDUSIA), which develops from the epidermal cells. Each sorus contains a considerable number of sporangia which are filled with tiny, brown spores (W. f. 54, *c*). Each sporangium consists of a stalk, or PEDICEL, by which it is attached to the leaf, and an enlarged CAPSULE containing the spores (W. f. 54, *d*, *e*). On one side of the capsule is a specialized ring of heavy tissue, the ANNULUS, which, when the spores are ripe, contracts and opens the capsule so that they can escape. Those which find a suitable environment germinate and form the sexual, or gametophyte, generation of the Fern.

SEXUAL GENERATION. The gametophyte generation of the Fern is a tiny, green, heart-shaped, leaf-like structure, known as the PROTHALLUS (W. f. 54, *f*). This term is used to designate it because it really resembles a Thallophyte type of plant in its structure, in that it has no differentia-

tion into the stem, leaves, or roots. The prothallus usually grows on the surface of the soil near the sporophyte, and as it is very small it is commonly not observed except by those to whom the life history of the Fern is known. On the under surface of the prothallus, which lies on the surface of the ground, numerous tiny rhizoids are found. The body of the leaf-like prothallus, when examined microscopically, will be found to consist of a mosaic of typical, chlorophyll-bearing cells. They vary somewhat in shape, but otherwise there is practically no differentiation except in those cells which form the sexual reproductive organs.

The reproductive organs of the prothallus are formed on the under surface, and they are similar in structure to the sexual organs already observed in the gametophyte of the Moss. The antheridia, in which the sperm develop, are spherical bodies distributed among the rhizoids (W. f. 54, *h*). The eggs are formed in archegonia, which are larger and more elongated than the antheridia (W. f. 54, *j*). The archegonia are located in a somewhat different region of the prothallus near an indentation, or notch, at one end (W. f. 54, *f*, *g*).

The sperm, when set free from the antheridia, are attracted to the egg cells in the archegonia, and as they are adapted for swimming, moisture must be present in order for them to reach and fuse with the eggs. Since they are borne on the under surface of the prothallus, which lies in contact with the soil, there is generally enough moisture present so that movements of the sperm can take place (W. f. 54, *i*).

When an egg in an archegonium has been fertilized by a sperm, the zygote begins to divide, and thus a young sporophyte is soon formed. The latter remains temporarily attached to the prothallus at the point where the egg lay in the archegonium. As the sporophyte enlarges and becomes able to nourish itself, the gametophyte degenerates and soon disappears (W. f. 54, *k*).

B. Life Processes of the Fern

The study of the structure of the sporophyte and gametophyte generations of the Fern reveals the fact that chlorophyll is present in both of them. They are, therefore, able to manufacture their own foodstuffs. The process of food manufacture in the leaves of the Fern and higher plants depends not only upon the presence of chlorophyll, but also upon the transportation of the raw materials, which have been taken in through the roots and then conveyed to the leaves. It is also necessary to transport the manufactured food materials from the leaves to various regions of the plant, where they can be utilized in repair, in growth, or, finally, in storing for future use. The further consideration of these and other physiological features may be deferred until a study of the Flowering Plants is undertaken.

XIV. FLOWERING PLANTS[1]

THE fourth and final phylum of plants is known as the SPERMATOPHYTA, a term which indicates that they are Seed Plants. They are more commonly known as the Flowering Plants. The Spermatophyta are divided into two main divisions, known as the GYMNOSPERMAE and the ANGIOSPERMAE, of which the former division is the more primitive. The term GYMNOSPERM refers to the fact that the seeds, which are formed by the plants belonging to this group, are not enclosed by other plant tissues. The group is not a very large one, comprising only about six hundred species. It includes the common evergreen, cone-bearing trees, such as the Spruces, Pines, and Cedars (W. p. 414).

The Angiosperms are a very large group of plants, comprising more than 135,000 different species, among which are included the great majority of the more common plants, both large and small. The term ANGIOSPERM refers to the fact that the seeds, which are formed by the plants belonging to this group, are enclosed by other plant tissues. The Angiospermae are further divided into two groups, known as the MONOCOTYLEDONEAE and the DICOTYLEDONEAE. This division is on the basis of the number of 'seed leaves,' or COTYLEDONS, which the embryo plant possesses, but there are various other structural differences. In the Monocotyledons, as the name indicates, the embryo has only one cotyledon. This group comprises some 25,000 species of plants, and for the most part they are small, grass-like, herbaceous forms such as the Grasses, and cereal plants like Corn, Wheat, Oats, etc. The tropical Palms are tree-like forms belonging to this group.

[1] Woodruff, pp. 61–90, 107–114.

In the Dicotyledons the embryo possesses two cotyledons. The structure of this group of plants is more advanced than that of any other, and a number of points of difference between them and the Monocotyledons may be noted. There are more than 110,000 different species of plants belonging to the Dicotyledons. These are commonly divided into some thirty-two different smaller groups, or orders, included in which are the great majority of familiar plants.

In considering the Spermatophytes, emphasis should be laid not only on the fact that they form seeds, but also upon the fact that they are composed of a number of very highly differentiated tissues. Beginning with a low type of Thallophyte plant, such as Spirogyra, in which the cells are all alike, there is a gradual development of the cell-groups, in the higher plants, to form tissues which are adapted for some particular function. This development in plants reaches the final stage in the Spermatophytes, in which groups of cells have become structurally modified, and form various types of specialized plant tissues each of which has a particular function to perform, such as protection, transportation, absorption, food manufacture, reproduction, etc. This process of cell differentiation and the formation of specialized tissues adapted for certain functions is also present in animal forms, where it is shown to even greater advantage than in plants. In the later study of the higher types of animals great emphasis will be laid upon this phase of living organization, for it is really the key to an understanding of the architecture of all the higher forms of life (W. pp. 59–60, 115–117).

The phenomenon of alternation of generations, which has been studied in the Moss and in the Fern, is, as has been stated, present in the Flowering Plants. There has been a continued increase in the development of the sporophyte generation. There has been, also, a continued degeneration of the gametophyte generation with the result that, in the Spermatophytes, it has become reduced to a highly special-

ized, parasitic structure of microscopic size, which is entirely unknown except to those who have studied the life-history of the Flowering Plants and understand its significance. The relative importance of the sporophyte and gametophyte is precisely the reverse of what it was found to be in the Moss. (W. f. 55.)

A. Seed

The ability of the Spermatophytes to form seeds is believed to have been one of the most important factors in bringing about the present success and dominating position of this group of plants. The seed may be defined as an embryonic sporophyte plant, in a resting condition, with a certain amount of food material stored in or around it. The protective structures of the seed are such that the embryo can withstand unfavorable environmental conditions of various kinds. Many seeds are also adapted so that they can be scattered by various agencies and thereby cause a wide distribution of the plant.

The seeds of the various Spermatophytes exhibit an almost endless variety of types. They may be large, such as the Cocoanut, which is the seed of a species of Palm tree. On the other hand, they may be as small as dust particles and require a microscopic examination to reveal their identity. Seeds may be of almost any shape, color, or texture. However, they all play the same part in the life of the plant; they are dormant young sporophytes awaiting favorable environmental conditions in order that the inactive embryo may begin to grow and form an independent, mature sporophyte (W. pp. 110–111).

Seeds fall within two general classes, depending upon whether the food material present is stored in the cotyledons of the embryo (EX-ALBUMINOUS) or outside the embryo (ALBUMINOUS) as ENDOSPERM. The ex-albuminous, or 'Bean type,' of seeds include those of such common plants as the Bean, Pumpkin, and Melon. The albuminous seeds are

found among both the Dicotyledons and Monocotyledons. The dicotyledonous albuminous seeds may be designated as the 'Buckwheat type,' and include the seeds of such plants as Buckwheat, Tomato, Tobacco, Coffee, Flax, and Castor Bean. Finally, the albuminous type of seed occurs in most of the Monocotyledons, and here belong the seeds of the 'Grass type,' including those of such plants as Grass, Corn, Wheat, Rice, Oats, and Barley. Technically, many of this last type are really fruits (p. 97), in that they are enclosed in some of the tissue of the parent plant.

In all types of seeds certain general structural features are present. There is an external protective covering, the SEED COAT, which is generally of a tough and resistant nature. This seed coat encloses the embryo and the stored food material (W. f. 62).

THE BEAN SEED. The structure of a typical dicotyledonous seed of the ex-albuminous type, such as that of the Bean, may now be considered. The seed coat forms a hard, glossy, resistant, outer covering which protects the embryo of the seed from drying and from mechanical injuries. The attachment of the seed to the parent plant during its development is indicated by a prominent scar, the HILUM, which may be noted on one edge of the seed. A seed which has been soaked in water for a while becomes somewhat swollen and softened, with the result that the seed coat can then be quite easily removed. The removal of the outer covering exposes the two large cotyledons of the embryo, which contain a considerable amount of food material and, in fact, constitute the great bulk of the Bean seed. Lying partially between and partially above the cotyledons is the small, unjointed stem-like body, or HYPOCOTYL, of the embryo, to one end of which the two cotyledons are attached. One end of the embryo bears two tiny folded leaves, the PLUMULE. From this region the stem and leaves develop. The opposite end of the embryo, the RADICLE, is somewhat pointed, and develops into the root system. (W. f. 27.)

THE CORN SEED. The structure of a monocotyledonous seed of the albuminous type may be studied in a kernel of Corn. On the outside is a protective coat. However, this outer covering of the Corn seed, known as the PERICARP, is of a different nature from that of the Bean. It is formed from a hardened portion of the wall of the ovule case in the parent plant, in which the seed was formed. The pericarp encloses the true seed coat of the Corn so closely that they cannot be separated.

The embryonic region of the Corn seed can be noted as a whitish area on one side, near the small end. The internal arrangement can best be observed by cutting the seed in halves in a longitudinal plane. An examination of one of the cut surfaces shows that the body of the seed is divided into two main regions; namely, the stored food material, or endosperm, and the embryo. The endosperm occupies the larger portion of the seed. It is divided into an outer portion, the hard endosperm, and an inner portion, the soft endosperm, which lies in contact with the embryo. Chemically, the endosperm is largely starch. The hard endosperm also contains, however, a considerable proportion of protein material in addition to the starch.

The embryo of the Corn seed lies to one side of the endosperm. It is essentially similar in structure to that of the Bean. There is a short, rod-like embryo differentiated at one end into the plumule, which is enclosed in a specialized sheath, the COLEOPTILE, and at the other end into the radicle from which develops the first root. Attached to the body of the embryo and lying in contact with the soft endosperm is an atypical cotyledon, known as the SCUTELLUM, which functions in the absorption of the endosperm, thus enabling the embryo to utilize this stored food material for growth.

THE GERMINATION OF SEEDS. With the general structure of the two types of seeds in mind, our next interest lies in the question of their development into an actively growing, in-

dependent plant. This occurs as the result of the process of GERMINATION. There are three essential things to be supplied to a seed before the latter can take place; namely, heat, moisture, and oxygen. And, of course, it is also necessary that the embryo be alive if germination is to take place. The length of time during which seeds will retain their vitality varies enormously in different plants. A few are known, like the Elm seed, which must germinate the same summer. Typically, however, seeds require a resting period over the winter, and then germinate the following spring if the proper conditions are supplied. Authentic cases are known where seeds nearly a century old have germinated, but there is no scientific confirmation of the statement that seeds present in mummy cases retain their power of germination.

Given the proper conditions, the viable seed will absorb a considerable amount of water, and, as a result, the embryonic tissues are then able to secrete certain enzymes. These act on the stored food materials and render them soluble so that they can be utilized by the developing tissues. Active metabolic processes begin, with the result that the dormant embryo becomes an actively growing plant. The result of these processes is, first, a rupturing of the seed coats from the swelling; second, the growth of the root tissues down into the soil; and, finally, the growth and differentiation of the shoot tissues, consisting of the stem and leaves, from the region of the plumule. The latter grow in an opposite direction from the root tissues and soon break through the soil, thus exposing themselves to the air and sunlight so that photosynthesis can begin. Germination is now finished and, as a result, the embryo has developed into an independent, sporophyte plant with a root system underground and a shoot system above ground. An immature plant at this stage is known as a SEEDLING, and its structure may now be considered.

B. Seedling

Bean Seedling. The structure of the Bean seedling is essentially that of almost any dicotyledonous seedling. The root of the seedling develops first as the result of the continued cell division of the embryonic tissue in the radicle (W. f. 27, *a*). A large central root is first formed, and this remains as the permanent basis of the entire ramifying root system which develops later. After the young plant is firmly anchored by the root, the real development of the shoot begins. There is a great elongation of the hypocotyl, and, in the Bean, the cotyledons are lifted entirely above ground (W. f. 27, *b*). The portion of the stem, with its leaves, which is above the cotyledons has all been formed as a result of the growth, by cell division, of the active embryonic tissues of the plumule. The first leaves to develop from the plumule are the two tiny ones which are to be seen folded together in the seed. The stem of the seedling as it develops is differentiated into two regions, known as the nodes and internodes. The nodes are the places on the stem from which the leaves and branches arise, and the internodes are the portions of the stem between the nodes.

Corn Seedling. There are certain differences to be noted between the Corn seedling and that of the Bean. In the first place, the endosperm of the Corn, which forms the bulk of the seed, remains below ground. In the Bean, this material, since it is within the cotyledons, is brought above ground by the elongation of the embryo. Also in the Corn seedling, the first, or primary, root which is developed by the embryo serves only as a temporary root. The permanent root system develops later from stem tissue. The plumule develops, as in the Bean, to form the shoot system, the stem of which is differentiated into nodes and internodes.

The body of the mature sporophyte plant which gradually develops from the seedling consists of a number of highly specialized tissues. All of these have arisen from three

fundamental tissues, known as EPIDERMIS, CORTEX, and STELE. These tissues may be thought of as being arranged in the form of cylinders. The outer cylinder is composed of the epidermal tissues, and it forms a protective covering over the entire plant. Lying within the epidermis is the middle cylinder composed of the cortical tissues. Finally, in the center of the plant are the tissues which constitute the central cylinder, or stele. The epidermis, cortex, and stele, although they are subject to considerable variation in the root, stem, and leaves of a plant, are continuous throughout its entire length. It will be advantageous now to consider specifically the structure and functions of these highly developed organs of the Spermatophytes (W. pp. 75–78).

C. Root [1]

The roots of a plant have two chief functions; namely, the absorption of water with various substances in solution from the soil, and firmly anchoring the plant to the soil. The root tissues are, in some cases, also adapted for the storage of food (W. f. 26).

The external structure of a typical root can be seen to advantage in a Radish seedling. It consists of the following regions: (1) At the extreme tip of the root is the ROOT CAP (W. f. 43, *a*) composed of an irregular mass of cells which form a protection for (2) the GROWING POINT which lies just above the root cap. The growing point of a root consists of actively dividing, undifferentiated, embryonic cells. These cells are the same type as those found in the tips of the stem and constitute the MERISTEM TISSUE (W. f. 43, *c*). Some of the embryonic cells formed in the growing point are supplied to the root cap to replace those torn away by pushing through the soil, but most of them are laid down as new root tissue above the growing point, where they soon become differentiated to form either epidermis, cortex, or stele. Thus as

[1] Woodruff, pp. 65–69, 78–80.

these cells grow to full size, the root is elongated, and the growing point, preceded by the root cap, is pushed farther and farther into the soil and away from the main body of the plant (W. f. 43, *d*, *d'*). (3) A certain distance above the growing point is the region of the ROOT HAIRS which are the specific absorptive structures of the plant. They occur in such profusion that the root in this region is enclosed in a white, felt-like mass. Each root hair, as is noted below, develops as a tubular, filamentous projection of a specialized epidermal cell. (4) Above the root hair zone the root loses its distinctive features and merges into the stem.

The microscopic study of a section of root, in the root hair zone, shows that each root hair is a definite prolongation of an epidermal cell (W. f. 44). A root hair may be described as a comparatively long, filamentous tube, projecting from one side of a cell. The epidermal cells, from which the root hairs develop, are typical in shape when first formed, but, later on, from the free surface of each cell, which lies in contact with the soil, a tiny projection grows out and gradually enlarges to form the root hair. The fully-formed root hair consists of an outer cellulose layer, which is continuous with the rest of the cell wall. Completely lining the cell wall, just as in a typical plant cell, is a layer of cytoplasm (W. f. 44, *b*). The latter surrounds a central vacuole which is continuous throughout the root hair and the body of the cell (W. f. 44, *a*). The cell nucleus lies near the tip of the root hair, embedded in the layer of cytoplasm (W. f. 44, *d*). The soil water and solutes pass through the cell wall and cytoplasm and into the cell vacuole, from whence it is passed on to the vascular tissue of the root.

D. STEM [1]

The stem has two main functions. In the first place it supports the leaves so that they can be fully exposed to the sunlight for photosynthesis, and, in the second place, certain

[1] Woodruff, pp. 69–70, 81.

stem tissues function in the transportation of raw materials from the roots to the leaves, and, also, of the manufactured food materials from the leaves to other various parts of the plant. The stem may also aid in the formation and storage of food materials.

There are several ways in which plant stems can be classified. In the first place they are either dicotyledonous or monocotyledonous, or they may be classified according to their length of life as ANNUALS, BIENNIALS, or PERENNIALS. An annual plant, such as the Bean or the Corn, dies at the end of one growing season and must develop anew from a seed (W. f. 27). The biennial plants, such as the Cabbage, Clover, and Turnip, take two years to complete their growth (W. f. 28). The first year the stem remains very short, but the second year it elongates and bears seeds. The perennial plants, such as the Trees, grow year after year. Finally, stems may be classified according to their position as either aërial or underground. The underground stem, or rhizome, of the Fern has already been noted.

Stems show the same fundamental plan of structure as do the roots, but, as a rule, the tissues of the former are more highly differentiated. In addition, certain other differences between stems and roots may be observed. First, the stem, as has been noted in the seedling, is divided into nodes and internodes, both of which are lacking in the roots. Second, the stem bears both leaves and flowers, neither of which are present on the roots. The structure of a high type of dicotyledonous stem may now be considered.

STEM OF ARISTOLOCHIA. Aristolochia is a climbing, dicotyledonous plant, commonly known as the "Dutchman's Pipe." A microscopic study of a transverse section of the stem of this plant reveals an outer, protective layer of epidermis (W. f. 45, *e*).[1] Lying within the epidermis, toward the

[1] This figure shows the structure of the stem of the Castor Bean, which is essentially the same as that of Aristolochia, but is not quite so highly differentiated.

center of the stem, is found the cortex (W. f. 45, *co*) which is differentiated into a strengthening tissue, the COLLENCHYMA, lying nearest to the epidermis, and the chlorophyll-bearing CHLORENCHYMA, which plays a part in food formation. Lying toward the center from these cortical tissues are those which are derived from the central cylinder. There is, first, a ring of SCLERENCHYMA which also contains some additional strengthening elements, then comes the VASCULAR BUNDLES with the CAMBIUM RING, and, finally, in the center of the section, the PITH (W. f. 45, *p*).

The vascular bundles are the conducting agents of the stem. They are composed of an outer portion, known as the PHLOEM, containing numerous SIEVE TUBES which transport the manufactured food materials of the plant (W. f. 45, *ph*). The inner portion of each vascular bundle is known as the XYLEM, and it contains larger tubes, through which the liquids containing inorganic salts in solution are transported from the roots to the chlorophyll-bearing tissues (W. f. 45, *x*). The phloem and xylem portions of the vascular bundles are separated in Aristolochia, and other dicotyledonous plants, by the actively growing cambium ring composed of meristem tissue (W. f. 45, *ca*). The cambium ring forms a continuous sheath of tissue in both root and stem, at the tips of which it merges into the cells of the growing points. The cambium tissue is not present in the leaves. Some of the newly formed cells of the cambium ring become differentiated into the outer portions of the stem, but most of them go to form the inner tissues. The stems of dicotyledonous plants are often known as EXOGENOUS STEMS because of the manner in which the new layers of tissue are laid down by the cambium ring on the outside of those already formed.

The pith lies in the center of the stem, enclosed by the cambium ring and the vascular bundles. It is composed of large, irregular cells which form a spongy, loose-textured tissue. The pith functions largely for storage of food materials, but

also, frequently, contains plant excretions in a crystalline form.

Woody Stem. Included among the Dicotyledons are the long-lived trees in which the bulk of the stems is composed of a woody tissue. The structure of the woody stems, while fundamentally the same as that present in other dicotyledonous plants, like Aristolochia, nevertheless shows some important modifications. The epidermis of trees is largely lost, and its function taken over by a heavy protective layer, known as the bark. The bark develops mostly from the cortical tissues and, generally, the phloem portion of the vascular bundles is also included. In a woody stem, therefore, the cambium ring lies just beneath the bark, at which point there is a very clear differentiation between the bark and the wood.

In the woody stems, a type of conducting tissue, known as the medullary rays, is present. These transport materials tranversely across the stem instead of up and down, as do the tubes in the vascular bundles. The medullary rays may also play a part in the storage of food materials.

The seasons of growth in the stem of a tree are indicated by the annual rings which mark the annual increase in the diameter of the stem. The annual rings are divided into two portions, the region of spring growth in which the woody tissue is more spongy, and the region of summer growth in which the woody tissue is more compact. Furthermore, the older portions of the stem tissue lying toward the center gradually change to a darker color, and are known as the heart-wood in distinction from the outer, newer portion of the stem, which is known as the sap-wood. The great mass of material present in a woody stem is non-living. The actively growing meristem tissues in such a stem are situated in the cambium ring just below the bark, and it is here that the new cells are continually being formed, most of which go to form the woody tissue of the stem, and a few to form the bark. As the new wood cells are laid down, the cambium ring continues to increase in diameter, and the

cells in the older portions of the stem gradually lose their protoplasm, the cell walls become very heavy and function either as woody tissue or as conducting elements. A woody stem contains only a comparatively small amount of pith.

MONOCOTYLEDONOUS STEM. The outstanding structural difference in the monocotyledonous stem lies in the arrangement of the vascular bundles, which have no definite order, but are irregularly scattered through the stem tissue. The continuous cambium ring of the dicotyledonous stem, in which growth takes place and around which the vascular bundles are regularly arranged, is entirely lacking in the Monocotyledons. Because of this, an indefinite increase in diameter does not occur in this kind of stem. Such a condition is characteristic of the Monocotyledons, and this type of stem is termed **ENDOGENOUS.**

A good example of the monocotyledonous stem is found in the Corn. The microscopic study of a transverse section through such a stem shows an outer layer of epidermal cells and then the cortical tissue, composed of several layers of thick-walled cells, underneath. The pith in this type of stem, instead of occupying a comparatively small area in the center, forms the bulk of the stem. The vascular bundles are irregularly scattered through the pith. They are known as the *closed* type of vascular bundle in contrast to the *open* type present in the Dicotyledons in which the cambium ring forms a common connecting link for all the vascular bundles. The structure of the conducting tissues in the vascular bundles is similar to that already studied in a dicotyledonous stem (W. f. 45, *ph*, *x*).

E. BUD[1]

A bud may be defined as an undeveloped shoot, or embryonic portion of the stem, with undeveloped leaves attached. Buds are formed at various points on a stem. The largest buds are those formed at the tips of the stem.

[1] Woodruff, pp. 72, 81–82.

These are known as TERMINAL BUDS (W. f. 35). The plumule in the seed constitutes the first terminal bud of the plant. Buds may be also formed at the nodes of the stem, in the angle between the leaf stalk and the stem (AXILLARY BUDS) (W. f. 35, *k*). In some cases, where more than one bud develops in an axil, the extra buds are known as ACCESSORY buds. Additional buds may also be formed in various irregular positions (ADVENTITIOUS BUDS). Buds may contain leaves (LEAF BUDS), or flowers (FLOWER BUDS), or both leaves and flower (MIXED BUDS). In buds of all types there is a definite arrangement, or VERNATION, of the embryonic leaves.

Buds may be either active or resting. An active bud is one in which growth is taking place. A resting bud is one in which growth has temporarily ceased because of unfavorable environmental conditions. The buds of some plants, like the Lilac, Horse Chestnut (W. f. 35), and Hickory, develop modified leaves which enclose the more sensitive tissues of the bud and protect them from freezing. Such a bud is known as the protected, or SCALY, type of bud. The buds of many other plants, such as Elodea, which do not develop a protective covering, are known as the unprotected, or NAKED, type of bud (W. f. 46).

A typical example of a naked bud is found in the common water plant, Elodea (p. 7). A median longitudinal section of a bud of this plant shows that it consists of a central stalk which is a continuation of the stem of the plant. It gradually tapers off and finally ends in a rather blunt GROWING POINT composed of actively dividing, embryonic cells of exactly the same type as is found in the growing point of the root (p. 83) and the cambium ring (p. 86) of the stem. This embryonic tissue wherever found is known as MERISTEM TISSUE. The growth of the meristem tissue in the growing points of the root and stem results in the elongation of the plant, and this is known as PRIMARY GROWTH. The growth of the meristem tissue in the cambium ring results in

an increase in the diameter of the plant, and is known as SECONDARY GROWTH.

On the central stalk of the bud, beginning just back of the growing point, the youngest leaves are to be seen as slight projections from the stem, which mark the nodes of the mature stem (W. f. 46). The leaves develop in a regular series, running from the youngest stage, which are nearest the growing point, to quite well-developed leaves attached to the stem some distance back from the growing point. The older leaves overarch and enclose the growing point and thus form the bud proper. This arrangement may be seen to advantage in a head of Cabbage or Lettuce, both of which are essentially large naked buds.

The bud of the Lilac may be taken as a typical example of the scaly type of bud. An examination of such a bud shows it to be covered and protected by atypical leaves, known as SCALE LEAVES, which have become brown and thick, and thus are so modified for protective purposes that they have largely lost their original leaf structure. When the scale leaves are removed, one by one, it can be noted that there is a gradual transition from the outer highly modified scale leaves to the tiny, typical green leaves toward the center of the bud. Thus the scale leaves enclose and protect the delicate tissues of both the inner leaves and the growing point of the bud from the cold of the winter season. In the spring when it is warm, and food materials are brought to the bud, the embryonic tissues in the leaves and growing point begin to grow and soon force their way out of the protective coverings. The Lilac bud contains both leaves and flowers and is, therefore, an example of a mixed bud.

F. LEAF[1]

Leaves are primarily the food-making organs of the plant. Their whole structure is built with the idea of presenting as

[1] Woodruff, pp. 71–75, 82–84.

large a surface as possible to the sun's rays, in order that the chlorenchyma tissue, containing the chlorophyll, may carry on photosynthesis. A leaf is composed of the flat, thin blade, or LAMINA, and the rod-like supporting stalk, or PETIOLE, which connects it to the stem of the plant. The petiole is somewhat enlarged where it connects with the stem and this forms the LEAF BASE. Growing out from the petiole near the leaf base are two tiny, leaf-like structures, known as the STIPULES (W. f. 34). The general external structure of a leaf and the mode of attachment to the stem are subject to considerable variation in different types of plants.

The leaf tissues can be classified, first, as the *protective tissues*, consisting of the epidermal cells, which form a covering over the leaf and, in fact, over all the other portions of a plant. Second, the *food-making* tissues, or chlorenchyma, which largely fills the interior of the leaf, and, finally, the *vascular tissue*, which ramifies all through the blade of the leaf and the petiole, down into the stem. The vascular tissue of the leaves is a direct continuation of the vascular bundles present in the stem, and may be noted externally as the VEINS. The arrangement of the veins, or VENATION, is different in the leaves of the Dicotyledons from what it is in the Monocotyledons. For example, in the Rose leaf, which is typical of dicotyledonous leaves, there is the netted-vein type of venation in which a large vein, the MIDRIB, runs through the center of the leaf. The midrib is a direct continuation, through the petiole, of the vascular tissues of the stem. It is very prominent on the under surface of the leaf. A great many lateral branches arise from the midrib, which in turn give off numerous fine veins, and thus a dense network of veins is formed which permeates the entire leaf surface (W. f. 34). In the monocotyledonous Corn leaf, the venation is the parallel-vein type in which there is no prominent midrib, and the veins, in general, are parallel to each other.

The epidermal cells, which form a covering over the entire leaf, are not merely for protection. Many of them, particularly on the under surface of a leaf, develop into specialized structures, known as the STOMATA (singular STOMA), through which the interchange of gases necessary for both photosynthesis and respiration takes place, and also through which water vapor is given off. This latter process, known as TRANSPIRATION, is a very important plant-process. In some leaves there are as many as 500 stomata per square mm. in the lower epidermis. A stoma consists of a very fine, slit-shaped opening between the walls of two specialized epidermal cells; the latter being known as the GUARD CELLS. They contain a small amount of chlorophyll, but their special feature lies in the fact that, when an insufficient supply of water is present in the plant, they can close the opening and thus prevent further loss by evaporation. When plenty of water is present, the guard cells are turgid, and spring back from the opening, thus permitting transpiration to take place.

The leaf is one of the most highly developed plant organs. A study of a transverse section of a typical leaf (*e.g.* Rose) will give a clear idea of the internal structure (W. f. 47). In such a section the epidermis will be seen as a single layer of heavy-walled cells forming the outer covering on both surfaces (W. f. 47, *e*, *e'*). In the epidermal layer of the under surface of the leaf can be seen the openings of some of the stomata between the guard cells (W. f. 47, *s*). Beginning with the upper surface of the leaf, just below the epidermis, there are one or two rows of quite large, regular-shaped, elongated cells, the PALISADE CELLS, placed with their long axes at right angles to the plane of the upper epidermis. They contain a large amount of chlorophyll, and constitute the main food-manufacturing cells of the leaf (W. f. 47, *p*).

Between the palisade cells and the lower epidermis there is an area of the leaf containing numerous cells which are

neither so large nor so regular in shape as the palisade cells. These cells constitute the spongy tissue, or SPONGY CHLORENCHYMA. The amount of chlorophyll present in this tissue is not so great as in the palisade cells (W. f. 47, *sp*). Between the cells of the spongy tissue are numerous, irregular air spaces, or LACUNAE, which communicate with each other (W. f. 47, *a*). Some of the lacunae, situated next to the lower epidermis, communicate to the exterior through the stomata. Thus it appears that the spongy tissue with the lacunae are mainly concerned with the interchange of gases through the stomata, and although the cells contain some chlorophyll, the manufacture of food is not their primary function.

The palisade cells together with the spongy tissue constitute the CHLORENCHYMA of the leaf, which, it will be remembered, is a modification of the cortical tissue of the stem (p. 86). The vascular tissue of the leaf, which has already been observed externally as the veins, consists of closed vascular bundles each composed of a xylem and a phloem portion (W. f. 47, *b*). The cambium tissue, which in the stem separates these two portions, is lacking in the leaves.

G. FLOWER [1]

The flower is a characteristic structure of the Spermatophytes, which is highly specialized for the purpose of reproduction. It is composed of whorls of modified leaves. These are borne on a somewhat modified portion of the stem, known as the RECEPTACLE (W. f. 58, *a*). The outermost whorl is made up of a number of green, leaf-like SEPALS, which, taken together, comprise the CALYX (W. f. 58, *b*). The sepals are largely protective in function, and form the outer covering of the flower bud; in some flowers the sepals are not separated, but are fused together to form a tube-like structure. The next whorl of the flower consists also of a

[1] Woodruff, pp. 74–75, 107–114.

number of leaf-like structures, the PETALS, which taken together constitute the COROLLA (W. f. 58, *c*). The petals are, however, of a more delicate texture than the sepals and are frequently very brightly colored. The calyx and corolla together constitute the floral envelope, or PERIANTH, which is an accessory part of the flower as distinguished from the essential parts which it encloses, namely, the stamens and the carpels.

The next whorl of modified leaves, the STAMENS, shows very little structural resemblance to typical leaves (W. f. 58, *d*; f. 59). Each is composed of a stalk, or FILAMENT, and a head, or ANTHER. The latter contains the POLLEN SACS (MICROSPORANGIA) in which are the microscopic pollen grains, or microspores, which, when they germinate, produce the male gametophyte (W. f. 61, *c*, *d*, *e*). Finally, the PISTIL, which is the central portion of the flower, may consist of one or more structures, the CARPELS (W. f. 58, *e*). A pistil which contains only one carpel is known as a simple pistil, one which comprises two or more fused carpels is a compound pistil (W. f. 60). Each carpel consists of an enlarged basal portion (OVULE CASE — commonly termed the ovary, a term which we shall reserve for the female gonad in animals) which rests on the receptacle of the stem. From the ovule case a stalk (STYLE) projects which terminates in an enlarged portion (STIGMA). The cells of the latter are able to secrete a substance to which the pollen grains will adhere when they come in contact with it. The ovule case of the pistil contains the ovules which, in turn, enclose the megaspores. These produce the female gametophyte. (W. fs. 40; 60, *f*.)

ALTERNATION OF GENERATIONS IN THE FLOWERING PLANTS. Having considered the structure of the flower in the preceding section, the next step is to link the latter with the life cycle of the Flowering Plant and thus complete the study of alternation of generations in plants, which has already been traced through the Moss and Fern.

The flower of the sporophyte, as noted above, produces

spores. These spores, contrary to what we have seen in the Mosses and common Ferns, are of two kinds; namely, the MICROSPORES, which are formed in the anthers of the stamens and produce the male gametophytes, and MEGASPORES, which are formed in the ovule case and produce the female gametophytes. The formation of two kinds of spores by a plant is known as HETEROSPORY (W. p. 106).

The pollen grains, or microspores, may each be regarded as a living cell, enclosed in a heavy protective wall. They are adapted for transfer by some external agency, such as the wind or insects, from the anthers of the flower where they are formed to the stigma of another flower. The pollen grains, when they are brought into contact with the sticky surface of the stigma, adhere to it. They also absorb moisture, the heavy outer wall breaks down, and the protoplasm contained in each pollen grain grows to form a long POLLEN TUBE (W. f. 61, *e*). The artificial germination of pollen grains can be brought about in a few hours by placing them in a weak sugar solution corresponding in strength to that present on the stigma.

The pollen tube grows down into the stigma, through the tissues of the style, and, finally, into the ovule case. Apparently the protoplasm at the end of the pollen tube is able to secrete certain enzymes which aid in dissolving the tissues of the pistil. A pollen grain when it is first formed in the anther contains only one nucleus. Later this nucleus divides to form three nuclei, two of which are concerned with fertilization and, therefore, represent the male gamete, or sperm. The third nucleus, known as the tube nucleus, has a different nature and function. It maintains a position near the tip of the growing pollen tube, and under its control the growth of the tube down into the ovule case takes place. The germinated pollen grain, with the pollen tube and the two enclosed sperm nuclei, constitutes the male gametophyte of the Flowering Plant (W. f. 61, *e*).

In a typical ovule case there are a number of multicellular

structures, known as OVULES. Each ovule consists of a main body, termed the NUCELLUS, which is attached to the wall of the ovule case by a stalk, the FUNICULUS, and is partly enclosed by certain plant tissues and integuments. In the nucellus is a specialized region, the EMBRYO SAC, consisting of a small group of seven or eight cells. This group of cells constitutes the female gametophyte. The embryo sac since it produces the female gametophyte is regarded as a megaspore, and the nucellus as the MEGASPORANGIUM (W. f. 61, *f*).

In the group of cells which constitute the female gametophyte, there is one which is larger than the others, and which occupies a position near to the attachment of the stalk. This is the female gamete, or egg cell, and it must be fertilized by a sperm cell in order to bring about further development. There is another cell in the gametophyte, known as the ENDOSPERM NUCLEUS, which is of particular importance because it forms the food material, or ENDOSPERM, of the seed.

To return to the male gametophyte: the pollen tube having grown down into the ovule case, the tip reaches the egg cell of the female gametophyte. The end of the pollen tube is dissolved and the sperm nuclei pass down and out of it. One of these nuclei fuses with the nucleus and thus fertilizes the egg cell. Following this the egg cell begins to divide, and the embryo thus formed, as a result of the sexual process, is a sporophyte. The other sperm nucleus fuses with the endosperm nucleus of the female gametophyte and, as a result of this, the food material is formed in close connection with the developing sporophyte embryo.

The growth of the sporophyte embryo and the formation of endosperm continues for a time. Then development stops, and the embryo with the stored food is covered by a seed coat which develops from the integuments of the ovule. This constitutes the seed stage with which we began our study of the seed-forming plants (W. f. 61, *g*, *h*). In a single ovule case as many seeds may be formed as there are ovules.

Growth having ceased, most seeds have a resting period, normally through the winter months, after which germination will take place, provided certain essential conditions are met, as noted above. Frequently the walls of the ovule case and associated structures, as a result of seed formation, become enlarged, and such a structure, containing the seeds, is known as a FRUIT.

H. Fruit

The formation of the fruit in a plant is dependent upon the processes of fertilization and the consequent formation of the seed with the enclosed embryo. If fertilization does not occur in a flower, the entire structure soon withers away. On the other hand, if fertilization takes place, there occur, along with the development of the seed, modifications of certain parts of the flower. Generally, these modifications are concerned with the walls of the ovule case, but other parts of the flower are also involved in some instances.

The term fruit, as understood by a botanist, has a broad meaning and includes many types which are not commonly designated as fruits. Fruits may be technically defined as ripened ovule cases, although other parts of the flower may also be involved (W. f. 27, *c*). In accordance with this definition, fruits include a great many varieties, ranging from the *dry fruits*, like the Peas, Beans, Nuts, and Cereals, to the *fleshy fruits*, like the Tomato, Pumpkin, Peach, Apple, and Berries. Thus among the fruits there is the greatest divergence in respect to many qualities, such as size, structure, color, and edibility. All fruits agree, however, in their fundamental purpose, namely, to protect the seeds and aid in their dissemination. The structure of a few representative types of fleshy fruits may now be noted.

Berry Type. This includes such fruits as Grapes, Blueberries, Cranberries, Tomatoes, Oranges, and Lemons. They are regarded as the simplest type of fleshy fruit. The fleshy, edible portion in this type of fruit is derived from the

walls of the ovule cases, together, in some cases, with certain enclosed structures. The seeds are present in the fleshy portion.

Stone Type. This includes such fruits as the Peach, Plum, and Cherry. In this type, the wall of the ovule case becomes differentiated into an outer fleshy portion and a hard inner portion. The latter portion constitutes the stone, or pit, and it surrounds the seed proper.

Pome Type. This includes such fruits as the Apple, Quince, and Pear. In this type, the fleshy edible portion of the fruit develops in the walls of the receptacle. The latter becomes greatly enlarged and entirely encloses the ovule case and seeds, which constitute the core of this type of fruit.

XV. HYDRA[1]

In Hydra we have our first example of a true METAZOÖN. It is small in size, simple in structure, and particularly well adapted for beginning a study of the multicellular animals, which will lead to the consideration of more and more complex animal types. There are several species of Hydra known, all of which live in fresh water, attached to water plants or to pieces of débris. They are large enough to be easily seen with the naked eye and, when expanded, appear as a rather flexible, tubular body with one end attached to some solid object, and the other end, bearing a number of fine tentacles, free and often waving back and forth. When contracted, the Hydra becomes a tiny spherical body.

A comparison of Hydra with Volvox shows that the cells which compose Hydra are much more highly specialized. It will be remembered that the previous study of Volvox showed that the cells of which it is composed have no specialization except for purposes of reproduction. Hydra, on the other hand, has numerous groups of cells which are specialized for various functions, such as nutrition, sensation, contraction, and reproduction. Such cells, since they are incapable of carrying on all the necessary functions of the organism, are said to have become physiologically unbalanced. Groups of such cells, which are similar, form a tissue. In the higher animals the tissues are grouped together to form organs (W. pp. 59–60).

A. STRUCTURE OF HYDRA

In its general structure, Hydra may be compared to a tubular sac (W. fs. 116, 64), the closed, attached end of

[1] Woodruff, pp. 118–121.

which is known as the FOOT, or BASAL DISK. At the opposite end of the tubular sac, known as the HYPOSTOME, there is a mouth-opening surrounded by several long, flexible tentacles. The exact number of tentacles varies in the different species of Hydra (W. fs. 64, *1*, *2*). The mouth opens directly into a single large central cavity, known as the ENTERIC CAVITY (W. f. 64, *7*). The tentacles also are hollow structures, and in each there is a cavity which is a continuation of the central enteric cavity. The body of Hydra is composed of a very large number of cells. These cells are clearly divided into an outer layer, known as the ECTODERM, which covers the entire animal, and an inner layer, known as the ENDODERM, which lines the entire enteric cavity even to the tips of the tentacles. Between the ectoderm and endoderm there is a thin layer of transparent, non-cellular material, known as the MESOGLOEA (W. f. 65).

Because of the fact that the body of Hydra and related forms is composed of two cellular layers, the ectoderm and endoderm, it is known as a DIPLOBLASTIC animal in contrast with the higher forms of TRIPLOBLASTIC animals, in which the body with the various organs arises from three cellular layers, ectoderm, endoderm, and a middle layer of mesoderm. In the triploblastic animals the very important and highly specialized layer of mesoderm lies between the ectoderm and endoderm. The ectoderm and endoderm of Hydra, together with the mesoderm of the triploblastic animals, are called the PRIMARY GERM LAYERS. In all forms of animals, they arise very early in development by a differentiation of the embryonic cells, and it is by continued differentiation of the cells of these primary germ layers that all the tissues and organs of the animal body are finally formed (W. p. 120).

ECTODERM. By far the greater number of the ectoderm cells of Hydra develop into the EPITHELIOMUSCULAR cells which form the covering, or EPITHELIUM, of the body. As indicated in their name, they contain contractile elements which function in a similar way to the muscle cells in the

higher types of animals. In the basal disk, some of the epitheliomuscular cells are modified for the purpose of secreting a sticky fluid which enables the Hydra to attach itself to various objects.

One end of these cells is generally somewhat larger than the other, and these large ends, closely fitted together, form the outer surface of the body. The inner portions of the cell bodies are generally not in contact with each other, as are the larger portions of the cells at the surface of the body. The spaces, bounded by the sides of the cells and by the mesogloea, often contain another type of ectodermal cell. This latter type of cells, on account of the position they occupy, are known as the INTERSTITIAL CELLS. Many of these interstitial cells remain as small, typically-shaped cells in the location described, but others become further differentiated into either CNIDOBLASTS or into specialized GERM CELLS.

The cnidoblasts are interstitial cells which have become highly modified to form the defensive and offensive weapons of Hydra, known as NEMATOCYSTS, or stinging capsules. The nematocysts are really quite remarkable structures. With the exception of the region of the basal disk, they are scattered in greater or less numbers over the entire surface of the body. They are present in the greatest numbers on the tentacles, where they are consolidated to form "batteries of nematocysts" which may be easily seen as bands encircling the tentacles (W. f. 64, *2*). Occupying the center of this type of cell is a very highly specialized structure, the nematocyst proper, which consists essentially of a long, coiled, filamentous tube attached to a spine-covered base. The long tube contains a poisonous substance. A rather rigid spine, the CNIDOCIL, projects from the outer surface of these cells into the water surrounding the animal. It is apparently sensitive to contact.

Under the proper conditions, the nematocyst can be exploded. When this occurs the coiled, poisoned tube

attached to the base bursts through the surface of the cnidoblast, 'uncoils' with great rapidity and with sufficient power to penetrate the tissues of various small animals with which Hydra comes into contact. In such a case the attacked animal, paralyzed by the action of the poison, is captured by the tentacles of Hydra and conveyed to the mouth. In addition to the type of nematocysts just described, which paralyze animals with a poison substance, there is another smaller type which shows the same general type of structure, but lacks the poison. The coiled filamentous tubes of this type of nematocyst curl around any small projecting part of an animal which the Hydra is attempting to capture, and in this way hold it firmly so that it can be conveyed to the mouth.

In addition to the epitheliomuscular cells and interstitial cells, there are also developed from the ectoderm a considerable number of NERVE CELLS which are scattered among the epitheliomuscular cells, and are also found lying deeper in the endoderm layer. The bodies of the nerve cells of Hydra have become somewhat modified in their structure from that of a typical cell in that they each possess processes which connect with other nerve cells and thus form a NERVE NET. The nerve net of Hydra really constitutes a specialized irritable tissue, just as does the nerve tissue of higher animals (W. fs. 99, 100, 102).

The chief function of nerve tissue in all animals, from the simplest forms to the most complex, is that of coördination. All the cells in an animal must work together for the good of the organism as a whole or it cannot survive. It is the nerve tissue which arranges this, unifying the various parts of an organism so that the necessary objects are attained. Take, for example, locomotion in Hydra. This is brought about by means of a coördinated movement of the muscular elements in various parts of the body under the direction of the nerve cells. Locomotion takes place in several different ways: first, the Hydra may move by a slow, creeping movement

in which the epitheliomuscular cells of basal disk alone are involved; second, the Hydra may stand on its head, so to speak, and move along by a coördinated movement of its tentacles, and, finally, it may move like a measuring worm by using both the basal disk and the tentacles. Whatever the type of locomotion, the actions of all the cells concerned are governed and coördinated by means of the nerve tissue, and the same thing is true for all the activities of the animal. (W. pp. 183–185.)

Endoderm. The structure of the endoderm cells, which line the enteric cavity, shows considerable variation from that of the ectoderm cells (W. f. 64, *6*). They are primarily nutritive in function. Some of them are actually able to take solid food particles within the cell body, just like a Protozoön does, and digest them (intracellular digestion). Other endoderm cells are able to secrete digestive enzymes into the large enteric cavity, which digest the food there (intercellular digestion). The latter method of digestion is fundamentally the same as that which takes place in the alimentary tract of all the higher animals (W. p. 157).

The endoderm cells, which are specialized for intracellular digestion, are somewhat larger than the epitheliomuscular cells of the ectoderm. Projecting from each of these cells into the enteric cavity are the flagella (W. f. 64, *6*). Temporary projections of the cell, known as pseudopodia, and similar to those in Amoeba, are also frequently formed. Both the flagella and pseudopodia apparently aid the cells in the capture of food particles. The internal structure of these cells varies somewhat, depending upon the amount of food which is present in the cell undergoing intracellular digestion. When the amount of food is small, large vacuoles develop in the cytoplasm. These are absent when food is present, and the cytoplasm then contains a large number of food vacuoles. The glandular endoderm cells, which secrete the enzymes into the enteric cavity, exhibit no noteworthy structural modifications from those found in a typical animal cell.

Interstitial cells also develop in the endoderm. These lie at the bases of the endoderm cells, next to the mesogloea, in much the same way as in the ectoderm layer.

B. Life Processes of Hydra

From the preceding discussion of the structure of Hydra it is evident that the cells have become structurally modified and variously adapted for the needs of the organism. Along with the structural modifications, the cells have become physiologically unbalanced and, therefore, individually incapable of carrying on all the vital activities necessary for the existence of an animal in the way, for example, the cell of an Amoeba or a Paramecium does. Thus as a result of the cell specialization there is a *division of labor*, and certain cells do certain things in the life of the organism as a whole, and in return are co-sharers in the benefits derived from the activities of the other specialized cells of the animal. We may now consider certain vital functions of Hydra and learn how these various activities are accomplished by the various types of specialized cells. (W. pp. 116–117.)

1. *Nutrition*

Hydra is chiefly a carnivorous animal, feeding upon a great variety of small, water-living animals. These are first paralyzed by the nematocysts and then conveyed by the flexible, muscular tentacles to the central mouth opening. The ectoderm cells of the tentacles are able to secrete a sticky substance which aids in holding the captured prey.

The food having been ingested, that is, passed through the mouth into the enteric cavity, the process of digestion begins. This may be either intracellular or intercellular, as noted above. It is probable that most of the food of Hydra is digested by the intercellular method. Thus to the endoderm cells is entrusted the nutrition of the entire Hydra. In the larger and more highly developed forms of animals a

specialized transport tissue, the blood, is necessary in order to carry the food absorbed from the alimentary canal to all the other cells of the animal body. In Hydra, however, this is not necessary, and the soluble food is passed by osmosis from cell to cell.

A certain proportion of the material ingested by a Hydra consists of inorganic material which is not capable of being digested. These indigestible substances are egested from the enteric cavity to the exterior through the mouth opening. This is the only opening into the digestive cavity of Hydra, and it serves, therefore, both as a mouth opening for the ingestion of food, and as an anal opening for the egestion of the refuse.

Symbiosis. Among the several well-known species of Hydra the common green form, *Hydra viridis*, is of particular interest from the standpoint of nutrition because of the fact that many of the endoderm cells of this species actually contain a great number of tiny, green plant cells belonging to a unicellular Algae, known as *Chlorella vulgaris*. The cells of this plant are what gives this species of Hydra its green color.

The interesting fact is that, although these plant cells are actually living in the cells of Hydra, they do not cause any harm to their host. On the contrary it appears that there is a mutual benefit derived from the partnership. A condition of this kind is known as symbiosis, and is to be distinguished from parasitism, in which one organism lives at the expense of another organism. The benefit to the plant arises from the fact that the metabolic wastes of the Hydra are just what is needed to carry on photosynthesis. On the other hand, as a result of the photosynthesis, an excess of oxygen is formed, and this the Hydra secures for its own life processes. It is also probable that the Hydra makes use of any surplus food which may be manufactured by the plant cells. At any rate, experimental work has shown that, by placing green Hydras in certain environments, it

is possible to get rid of the Alga cells. The green Hydras under such conditions become white, and although they are able to live, they do not show so great vitality as do other Hydras of the same species in which the symbiotic condition is maintained. (W. pp. 331–338.)

2. *Respiration and Excretion*

There are no specialized organs of excretion in Hydra. Each of the cells apparently attends to the excretion of its own metabolic wastes just as the protozoan cells do. Respiration is carried on through the permeable cell walls and takes place both at the surfaces of the ectoderm cells, which are in contact with the surrounding water, and also at the surfaces of endoderm cells, which are in contact with the fluids of the enteric cavity. Excretion of the liquid metabolic wastes, containing soluble salts and nitrogenous material, also takes place directly through the cell walls; a specialized excretory apparatus, like the contractile vacuoles of the Protozoa, is not present in the cells of Hydra.

3. *Reproduction*

Reproduction in Hydra may take place either asexually or sexually. The common asexual method is known as BUDDING, and is a process which may often be observed in actively growing individuals. The basis of this process is, of course, just as in the Protozoa, a balance in favor of the constructive phase of metabolism. As a result certain cells in the body wall, generally near the basal disk, begin to divide rapidly and soon form a small swelling, which projects from the ectoderm (W. f. 64, *3*). This projection continues to increase in size and soon shows a differentiation into the body proper and into tentacles which surround a central mouth opening; in other words, the bud now looks like a small, attached Hydra. During the formation of the bud, both the body wall and enteric cavity of the bud are continuous with the

corresponding parts of the parent Hydra. A section through it shows that the body wall is made up of ectoderm, mesogloea, and endoderm, just as is the body wall of the parent Hydra, surrounding a central enteric cavity (W. f. 64, *4*). When the bud is fully developed the attachment with the parent Hydra is broken, a basal disk is developed, and the new individual begins an independent existence (W. p. 217).

In addition to asexual reproduction by budding it is also stated by some authorities that Hydra may reproduce by fission — that is, by a division of the entire animal into two. The division is generally along the longitudinal axis. It begins at the distal, or tentacle, end of the animal and proceeds toward the basal disk (W. f. 116).

In connection with the asexual reproduction of Hydra, consideration should be given to the remarkable power of regeneration which this animal possesses. Regeneration may be defined as "the ability of an organism to replace, or regenerate, missing parts in order to restore again the perfect whole." The ability to regenerate lost parts varies greatly in different kinds of animals, but, in general, the ability exists in inverse ratio to the amount of cell specialization which is present. In other words, the higher the development of an animal, the less is its power of regeneration. Hydra is a comparatively simple type of Metazoön, and experiments on this organism have shown that it possesses a very high degree of regenerative ability. Hydra can be cut into several pieces — four or even more, and in many different planes — and each of these pieces will regenerate the missing parts in a short time. Thus, as a result of sectioning the animal and the power of regeneration which the tissues possess, there will be several individuals where there was at first only one. The process of regeneration in such cases really results in asexual reproduction. (W. pp. 220–222.)

Sexual Reproduction. Under certain conditions, which are not fully understood, a Hydra may develop definite male

and female gonads, both of which are temporary structures. Thus, the same individual produces both sperm and eggs. The majority of animals produce either sperm or eggs. A form which produces both sperm and eggs is known as an HERMAPHRODITE (W. pp. 203–204).

The male gonads, or testes, in which the sperm are formed, develop as swellings in the ectoderm of the body wall, just below the tentacles (W. f. 64, *8*). The testis consists of an outer covering of ectoderm cells, which encloses a great number of the developing sperm cells. The latter arise, as has been noted, from modified interstitial cells. By repeated divisions of the latter a very large number of immature sperm cells are formed. These undergo radical structural modifications, finally resulting in the formation of mature, free-swimming sperm which break forth from the gonad. They swim about freely in the water, and when one comes into contact with a mature unfertilized egg, it penetrates the egg membranes, thus permitting the permanent union of the male nucleus with the female nucleus, that is, fertilization, to occur. (W. f. 115, *C*.)

The ovaries of Hydra also develop as swellings in the ectoderm of the body wall. They are, however, located farther from the tentacles than are the testes (W. f. 64, *9*). The eggs in the ovaries likewise develop from the interstitial cells. The process, however, is different from that which takes place in the formation of the sperm. In the first place there is usually only one egg formed in an ovary, whereas there are an enormous number of sperm formed in a testis. In the early stages, an ovary of Hydra contains a large number of potential egg cells which have developed from the interstitial cells, but only one of these finally forms a mature egg cell, while the others aid in its nourishment. Some of the sister cells are actually engulfed by the amoeba-like pseudopodia which develop on the egg cell. The latter becomes very large as a result of the nourishment supplied by the other cells. In its general shape and structure it is quite like a

typical cell and very different from the atypical sperm cells. The large, mature egg projects through the ectoderm of the Hydra, surrounded only by a thin egg membrane, and there it awaits the sperm. It remains attached to the ectoderm at this point for some time even after fertilization has occurred. During later development it breaks away and becomes entirely free from the parent body. The sperm and eggs of a Hydra do not mature at the same time and, therefore, the eggs are not fertilized by the sperm of the same individual (W. f. 115, *C*).

The process of fertilization in the egg of Hydra furnishes not only the method by which, as a result of the fusion of the chromatin material, the characteristics from two parents may intermingle, but also the stimulus for cell division. This same thing is true, in general, for all living organisms, including Man. Each starts its independent existence as a single egg cell which, when fertilized by a sperm, begins to divide by mitotic cell division, the process being known as CLEAVAGE (W. pp. 54–60). As a result of cleavage, two cells, then four, eight, sixteen, etc., are formed (W. f. 19). These cells remain attached to each other and, in Hydra, in a short time, when about 128 cells are present, it is found that they are arranged in the form of a hollow sphere — the wall of which is composed of a mosaic of cells closely fitted together. This stage in the development of Hydra or other forms is known as a BLASTULA and it is broadly comparable with the permanent structure of Volvox, previously studied (W. f. 19, *F*; f. 18, A).

In the development of Hydra the blastula is only a transient condition. The ectoderm cells, of which the wall of the blastula is composed, continue to divide and soon form a special group of cells at one pole of the sphere. These cells are somewhat differentiated from the outer ectoderm cells, and they are destined to form the inner layer, endoderm, which, as will be remembered, lines the enteric cavity and has as its chief function the digestion of food materials. The young

Hydra, in this two-layered, or diblastic, condition, with outer ectoderm and inner endoderm, is known as a GASTRULA (W. f. 19, *G*, *H*, *I*). Hydra remains essentially as a permanent gastrula made up of the two cellular layers, ectoderm and endoderm, separated by a very thin non-cellular material, the mesogloea. It is important to note that the two-layered gastrula stage, which is permanent for Hydra, is only a temporary condition for the higher triploblastic animals, all of which develop the important third cellular layer, the mesoderm.

After gastrulation the embryo forms a thin inner membrane and a thick, outer chitinous shell — both of which are products of the ectoderm cells — becomes free from the parent and falls to the bottom of the pond. Later the embryo emerges from the shell, develops tentacles, and the ectoderm and endoderm cells become otherwise modified to form the mature Hydra.

XVI. OBELIA[1]

Obelia is a marine animal and a typical representative of a considerable number of species of Coelenterate animals which exhibit the phenomenon of alternation of generations, or metagenesis, as this process is often called in animals. There is an alternation in the life history of this form between an attached, colonial, asexual stage and a free-swimming, sexual, medusa stage. Obelia also shows a somewhat higher degree of cellular specialization than does Hydra, to which form it is closely related (W. p. 414).

A. Structure of the Asexual Stage of Obelia

The general appearance of the asexual colonial form of this animal is *superficially* plant-like. It consists of a colony of attached individuals, termed zooids, which are connected by a common stalk (W. f. 118, *A*). The stalk is differentiated into two portions: first, the part known as the hydrorhiza, which is attached to some convenient solid object in the water; and second, the branches, or hydrocauli, which arise from the hydrorhiza and bear the hydranths at their tips. Both of these portions of the stalk are composed of an outer, transparent, exoskeletal sheath, the perisarc, which is non-living, and an inner, living portion, the coenosarc, which is continuous with the living material of the hydranths (W. f. 118, *A: 5, 6*).

The zooids composing a typical, fully-developed colony are of two kinds. There are, first, the nutritive zooids, or hydranths, each of which, from a structural standpoint, may be regarded as comparable to a separate Hydra with a stalk attached, and second, the reproductive zooids, or gonangia, which have become greatly modified for the purpose of

[1] Woodruff, pp. 217–220.

asexual reproduction and are dependent upon the nutritive zooids for their nutrition.

The body wall of a zooid is composed, like that of Hydra, of an outer layer of ectoderm and an inner layer of endoderm (W. f. 118, *A : 1, 2*). Between these two layers there is a thin layer of the non-cellular mesogloea. Tentacles are present and surround a central mouth opening which leads into the enteric cavity. The living coenosarc, which is continuous throughout the colony, has the same structure as does the body wall of a zooid, and it is to be regarded in fact as a continuation of the body wall of the zooid (W. f. 118, *A : 3, 4*). In other words, the bodies of the hydra-like zooids can be thought of as having become differentiated into an anterior portion, the hydranths proper, and a greatly elongated, posterior portion, the coenosarc. Surrounding the entire colony is the non-living perisarc, formed as a secretion by the ectoderm cells (W. f. 118, *A : 6, 7, 10*).

In a young colony of Obelia, all of the zooids are of the nutritive type, but, as a colony gets older, the gonangia are formed, which are specialized for the sole purpose of asexual reproduction. They are club-shaped and consist of an outer covering (GONOTHECA) which is a continuation of the perisarc, and an inner portion (BLASTOSTYLE) which is a continuation of the living coenosarc of the stalk. On this central, club-shaped blastostyle, a number of little swellings, the MEDUSA BUDS, appear, each of which develops, while still attached to the blastostyle, into a tiny jellyfish, or MEDUSA. When fully formed, the medusae become detached from the blastostyle and float out through an opening in the distal end of the gonotheca, and each takes up its independent existence (W. f. 118, *A : 8, 9*).

B. Structure of the Sexual Stage of Obelia

Inasmuch as the medusae of Obelia are very small, we shall describe another species of medusa, known as Gonione-

MUS. The latter has practically the same structure as a medusa of Obelia, but is more easily studied (W. f. 118, B).

Gonionemus resembles in shape a flattened dome or umbrella when seen from a side view (W. f. 119, *B*). The outer convex surface is called the ex-umbrella, or aboral, surface. Attached to the edge of the 'umbrella' are numerous tentacles. The under, concave surface is called the sub-umbrella, or oral, surface. The opening on the oral surface is partly closed by a circular, perforated membrane, the VELUM, which is attached near the base of the tentacles (W. f. 119, *B: v*).

Suspended from the center of the oral surface is the MANUBRIUM, which ends in a wide-lipped mouth (W. f. 118, *B: 1*). The lips are known as the ORAL LOBES. The manubrium, near its attachment to the oral surface of the body, merges into four RADIAL CANALS. These run at right angles to each other from the manubrium to the edge of the body near where the tentacles are attached, and there they connect with the CIRCULAR CANAL which encircles the body. The enteric cavity, which begins in the manubrium, is continuous throughout the radial and circular canals. The sexual reproductive organs, or gonads, are suspended from the radial canals, and they may be either male or female. The sexes are separate in Gonionemus, and the condition is, therefore, unlike that in Hydra (W. f. 118, *B: 3, 4*).

ECTODERM. The body of Gonionemus is similar in construction to that of all Coelenterates. It consists of an outer layer of ectoderm and an inner layer of endoderm. The two cellular layers are separated by the non-cellular mesogloea. The cells of the ectoderm form an outer covering over the entire body, including the oral and aboral surfaces and tentacles. The nematocysts are confined to the tentacles. The tentacles also bear a number of adhesive disks which arise as modifications of the ectoderm cells.

The ectodermal nerve cells are more highly developed in Gonionemus than in Hydra, and both SENSORY and MOTOR nerve cells are present. In the ectoderm near the attachment

of the velum, the nerve cells are grouped to form the NERVE RINGS. The latter encircle the body in the region near the circular canal. The cells of the nerve ring are chiefly motor in function (W. f. 119, *B* : *nv*, *nv'*). Two types of specialized sense organs are formed in the ectoderm. At the base of each tentacle there is a spherical cavity containing pigmented ectodermal cells, while between the bases of the tentacles appear small, solid, ectodermal outgrowths, known as STATOCYSTS, which are believed to function as organs of equilibration (W. f. 118, *B* : *5*). The sense organs of Obelia are able to receive certain stimuli from the environment and pass an impulse on to the inner nerve cells. This is exactly what the sense organs do in the higher animals.

The stimuli received by the sensory cells are also able to bring about a high type of coördinated swimming movement. In swimming, there is a rhythmic contraction of the entire body brought about by the muscular elements present in the cells of both the ectoderm and the endoderm, under the control of the motor nerve cells. The contraction results in a decrease in the volume of the oral space between the velum and the top of the oral surface. A portion of the water which fills this space is thus driven out with considerable force through the central opening in the velum (W. f. 119, *B*). As a result, the animal is driven forward, that is, aborally, at each contraction. As soon as the water has been forced out the contraction ceases, the oval space again assumes normal size, and is filled with water as at first. This rhythmic, swimming movement in Gonionemus presents a high type of coördination between the nerve and muscle elements.

ENDODERM. The inner layer of endoderm cells forms the lining of the main enteric cavity in the manubrium as well as its continuation in the radial and circular canals. These cells have the same structure and function as in Hydra. The non-cellular, secreted mesogloea, lying between the ectoderm and endoderm, has the same general character in all Coelen-

terates, but in Gonionemus and other jellyfishes a very much greater amount is present than in the Hydra-like animals. It really forms the larger part of the body wall in these types; that is, the body wall may be said to consist of a thick layer of mesogloea, covered on the outside by a thin layer of ectoderm cells and on the inside by a thin layer of endoderm cells (W. f. 119, *B: msgl*).

While at first glance one fails to observe any great similarity between the structure of Hydra and that of a medusoid form like Gonionemus, nevertheless, both are built upon the same fundamental body plan. The jellyfish type is more flattened than the Hydra type, but the various parts of the body occupy practically the same position in the two forms, the greatest difference between the two being the relatively large amount of mesogloea present in the medusa type. (W. f. 119.)

C. Life Processes of Obelia

1. *Nutrition*

In the attached, colonial stage of Obelia, the various processes involved in the capture, ingestion, digestion, and assimilation of food, as well as egestion and excretion, are so nearly like those of Hydra that no general description is necessary. Any surplus of food from the nutritive zooids goes by way of the coenosarc to the support of the colony as a whole, particularly for the development of the stalk and the reproductive zooids.

In the free-swimming medusae there are certain methods of food capture, which should be noted. Gonionemus secures its food in two ways. When it is moving through the water, the food which comes in contact with the tentacles is captured and conveyed to the mouth by them. These tentacles, owing to the sensory nerve cells which are scattered through the ectoderm, are very sensitive to stimuli, and small animals, which come into contact with them, bring

about a quick response. There is an explosion of the nematocysts, and the prey is at once paralyzed by the poisoned stinging hairs. It is then conveyed to the mouth by the tentacles. Gonionemus also feeds when it is quiet. This method of feeding can be demonstrated with a living specimen in a small dish of sea water. The animal, when quiescent, lies on the bottom of the dish with the oral surface up. In this position the tentacles and the oral lobes of the manubrium are able to secure any bits of food that may fall on them from the surface of the water. For example, bits of clam meat may be dropped on the animal, and their capture and ingestion easily seen. Any food captured by the animal is taken into the enteric cavity through the mouth. Digestion as in Hydra occurs both by intracellular and intercellular methods. A portion of the food passes from the enteric cavity, or 'stomach,' at the base of the manubrium, through the radial and circular canals where it is absorbed, and thus the entire organism is nourished.

2. *Reproduction*

The reproduction of the colonial Obelia is entirely asexual, and may take place either by a budding and growth of the stalk or by the formation of specialized medusa buds in the reproductive zooids.

In the first type mentioned in which the stalk buds, the hydrorhiza of an Obelia colony grow along the substratum to which the colony is attached. At certain intervals the upright stems, or hydrocauli, which bear the zooids, are formed from the hydrorhiza. The nutritive zooids thus formed furnish an additional supply of food material so that the hydrorhiza can continue to grow.

In the formation of medusa buds, Obelia exhibits a highly specialized type of asexual reproduction which leads directly to the consideration of the phenomenon of alternation of generations. The free-swimming medusa, produced in the

reproductive zooids by asexual budding, develop either ovaries or testes. The gonads of either sex are attached, as previously stated, to the radial canals of the medusa, and no external morphological differentiation is to be noted between the two sexes. When sexually mature, the eggs break out of the ovary of a female medusa directly into the sea water. Similarly, from the testes of a male, active sperm are liberated. These swim freely through the water to the eggs, and fertilization, followed by cleavage, occurs as in Hydra. The result of the first stages in development is the formation of a tiny, ciliated embryo, known as the PLANULA (W. f. 118, *C*). The planula swims around for a time, then becomes attached to some suitable solid material in the water. It soon begins to change its form and to develop into the attached, colonial asexual phase of Obelia with which we began the study of the life history.

XVII. EARTHWORM[1]

The common, widely distributed Earthworm is a good example of a large group of segmented worms, known as the Annelida, which are present in the soil practically all over the world. Due to the fact that the Earthworm possesses a number of structural features which are of considerable importance in interpreting those of the higher types of animal life, it is a particularly valuable form for study. These structural features may be enumerated as follows:

(1) The Earthworm is a triploblastic animal; the three primary germ layers, ectoderm, mesoderm, and endoderm, being present as in higher animals, and in contrast to diploblastic animals like Hydra (W. p. 120).

(2) The Earthworm shows a definite segmentation, or metamerism of the body; that is to say, the body is composed of a large number of distinct segments which are known as somites, or metameres. Varying degrees of segmentation are present in the higher forms of animals (W. p. 121).

(3) The Earthworm possesses a body cavity, or coelom, lying between the body-wall and the tubular alimentary canal. Thus, the body plan may be described as a tube within a tube. This type of structure is present in higher forms, but it is not found in the Coelenterates, in which the body may be said to consist of a single tube (W. p. 121).

(4) The Earthworm shows a bilateral symmetry which means a two-sided, or right and left, symmetry. As a rule, the organs in such a case are paired; one on the right side of the body and one on the left side. In such animals there

[1] Woodruff, pp. 121–129.

is only one plane which will divide the animal into symmetrical halves. Bilateral symmetry is still more pronounced in the higher animal types (W. pp. 122–124).

(5) The Earthworm possesses a number of definite systems of organs for performing various necessary functions, such as nutrition, circulation, excretion, reproduction, sensation, and movement (W. pp. 59–60).

A. External Structure

The common Earthworm has an elongated, cylindrical, segmented body which varies in length from a few inches to approximately a foot. Other species of Earthworms are known which may reach a length of two or three feet. One end of the body tapers down to a somewhat blunt point in contrast to the opposite end, which is somewhat flattened. A study of the animal shows that the more pointed end is the anterior, or head, end, and the opposite is the posterior, or tail, end. The Earthworm may be said, therefore, to show an *anteroposterior differentiation*, or, in other words, a difference between the two ends. Furthermore, the worm, when crawling along, maintains as a general rule the same part of the body in contact with the solid surface. An examination of the body will show that this lower, or ventral, surface on which the worm crawls is somewhat flattened as compared with the upper, or dorsal, surface. A differentiation between these two surfaces, as shown in the Earthworm, is known as *dorsoventral differentiation.*

The number of segments present in the body varies considerably in individual worms, but all the segments have essentially the same structure. Certain differences, however, may be noted. The first segment at the anterior end of the body has an overhanging dorsal projection, known as the PROSTOMIUM, which forms a lip-like structure over the mouth (W. f. 67, *5*). In the last segment of the body is the slit-shaped anal opening. About one-third of the distance back

from the anterior end a few segments are differentiated to form a swollen glandular structure, termed the CLITELLUM, which functions in connection with reproduction.

If an Earthworm is grasped by one hand, and the body drawn through the fingers of the other hand, a roughness will be noted. This is due to the presence in each segment of tiny bristles, or SETAE, which project through definite openings in the skin. Each segment has eight setae arranged in four pairs. The setae are in corresponding positions in each segment, so that four double rows of setae are formed which run the entire length of the body. Two of the double rows are on the ventral surface, one double row on the right, and one on the left side.

STRUCTURE OF THE BODY WALL. A microscopical examination of a prepared transverse section through the body wall of the Earthworm shows that it consists of five layers, as follows (W. f. 68):

(1) The outermost layer consists of a very thin, transparent membrane, known as the CUTICLE. This is not a cellular layer, but is formed as a secretion by (2) the epidermal cells which lie directly underneath. Most of the epidermal cells contain pigment, especially those on the dorsal side of the animal, with the result that the animal is somewhat darker on the dorsal side. Many of the epidermal cells are able to secrete a mucus which, passing out through openings in the cuticle, covers the body. Sensory cells are present in the epidermis (W. f. 101, *sc*). (3) The next layer of the body wall consists of circular muscle tissue. This layer is formed from a great many long, spindle-shaped muscle cells which are so arranged that when they contract the diameter of the body is decreased. (4) Beneath the circular muscle layer is a thick layer of longitudinal muscle tissue in which the cells are arranged with their long axes parallel to the long axis of the body so that when they contract they cause a decrease in the length of the animal. (5) The innermost layer of the body wall is known as the COELOMIC EPITHELIUM.

It consists of a single layer of flattened epithelial cells which line the coelom.

In a transverse section, the finer structure of the setae, which are present in each segment, may be observed. Each seta consists of a single bristle embedded in the body wall (W. f. 68, *set*). It is long enough to project a slight distance beyond the exterior surface of the body at one end and, at the other end, to project into the coelomic cavity. The basal end of each seta is covered over by a number of muscle fibers which are attached to the nearby body wall. The arrangement and attachment of the muscle fibers to the setae is similar in each case, and is of such a nature that the ends of the setae, which project externally through the body wall, can be pointed either anteriorly or posteriorly by a contraction of the proper fibers. The result is that they can be used by the worm as an aid in locomotion.

B. Internal Organs

In the worm, the coelom is not a single, open space running from the anterior to the posterior end of the body, but is divided into as many compartments as there are segments in the body. These divisions of the coelom are due to membranous, dividing walls, or SEPTA, which are attached both to the body wall and to the alimentary canal. Each of the segmental grooves, which can be seen on the external surface of an Earthworm, mark the place of attachment of a septum. (W. fs. 66, *A*, *B;* 66, *C: ds*; 67, *4*.)

1. *Alimentary Canal*

Beginning with the mouth opening at the extreme anterior end of the body, the alimentary canal continues as a closed tube throughout the entire length of the animal, and finally ends at the anal opening situated at the extreme posterior end. The following regions are present:

The PHARYNX extends from the mouth to the sixth segment. It is a heavy-walled, spindle-shaped structure and is attached to the body wall by a great many fine muscular fibers (W. f. 67, *7*, *8*, *9*).

The OESOPHAGUS begins at the posterior end of the pharynx in the region of the sixth segment and continues posteriorly as a thin-walled, undifferentiated tube to the fourteenth segment, where it connects with the crop and gizzard. Three pairs of CALCIFEROUS GLANDS open into the oesophagus near its posterior end (W. f. 67, *10*, *11*, *15*, *16*).

The CROP and GIZZARD constitute sac-like enlargements of the alimentary canal lying between segments 14 and 18. Although of about the same size and shape, these two organs differ considerably in structure. The crop is thin-walled and elastic and serves for the temporary storage of food, whereas the gizzard has heavy, muscular walls, and is adapted for grinding the food (W. f. 67, *12*, *13*).

The INTESTINE has its beginning at about the 18th segment and continues as a straight, thin-walled tube to the posterior end of the body, where it ends at the anal opening. In each segment there is a slight out-pouching of the intestinal wall (W. f. 67, *14*).

STRUCTURE OF THE INTESTINAL WALL. A microscopic examination of a prepared transverse section through the alimentary canal of an Earthworm, in the region of the intestine, shows the following arrangement of tissues (W. f. 68):

The transverse section is nearly circular in outline. The central cavity, or lumen, of the intestine is partly filled by an infolding of glandular and absorptive tissue from the dorsal wall, thus forming the TYPHLOSOLE, which runs practically the entire length of the intestine and greatly increases the absorptive surface of the latter (W. f. 68, *typh*).

The outer surface of the alimentary canal is covered by a layer of large, irregularly-shaped gland cells, known as the CHLORAGOGUE LAYER, which contain a large number of

yellowish-green pigment granules scattered through their cytoplasm. The layer of chloragogue cells continues into the typhlosole and, indeed, forms the greater portion of this structure (W. f. 68, *hep*).

Lying just within the chloragogue layer is a layer of circular muscle tissue which forms a band running entirely around the intestine. Just as in the body wall, the contraction of the muscle fibers of this layer brings about a reduction in the diameter of the alimentary tract. Numerous bundles of muscle fibers, running lengthwise of the alimentary canal, lie below the circular muscular layer. They do not form so definite a layer as the circular muscles, and are arranged in a somewhat irregular fashion. Numerous blood vessels are present in the muscle tissue of the intestine. These vessels break up into many very fine, thin-walled branches, the CAPILLARIES. The latter receive the absorbed food materials and pass them on to the other larger vessels which transport them to all parts of the body.

The innermost layer of the alimentary canal, known as the LINING EPITHELIUM, is composed of endoderm cells which are responsible primarily both for the digestion of the food material and its absorption after it has been digested. There are in fact two types of these endoderm cells, the gland cells and the absorptive cells. The gland cells secrete digestive ferments, or enzymes, which are comparable to those present in other animal forms, and have the power to change, or digest, the food so that it can be absorbed. The gland cells vary considerably in size and shape, depending upon the amount of material they contain. The absorptive cells are quite regularly arranged between the gland cells. They are adapted for absorbing the digested food material from the cavity of the intestine and transferring it to the blood stream for transportation to all parts of the body. The bodies of the absorptive cells are quite large, and the free ends, which with the gland cells line the intestine, are ciliated.

PHYSIOLOGY. The Earthworm, as its name indicates, is

adapted for living in the soil. The holes, or burrows, which it makes, vary in depth from a few inches to several feet, depending upon the nature of the soil. In all cases, the burrows are formed by the Earthworm literally 'eating a hole' in the soil. All the materials from the burrow are taken into the alimentary canal through the mouth opening, passed through the entire length of the canal, and finally egested through the anal opening as castings, or faeces. The castings are voided around the hole at the surface of the soil, where they form little mounds of earth. The great number of Earthworms present in the soil of many regions, together with their habit of almost continual burrowing, makes it possible for them thus to bring considerable quantities of soil from lower depths to the surface. It has been estimated that, in some localities, as much as 18 tons of soil per acre is annually brought to the surface in this manner.

This method of burrowing, by eating through the soil, not only provides the Earthworm with a method of home-building, but it also constitutes an important source of its food supply, for, as the soil passes through the alimentary canal, much of the organic material there present is utilized for food, while the indigestible inorganic material of the soil passes on out of the body as faeces. In addition to obtaining food from the materials in the soil, the Earthworm when it comes to the surface, generally at night, secures other organic materials which can be utilized for food.

In the ingestion of food material the muscular pharynx plays a great part. When the mouth is applied to some suitable object, the muscle fibers, which run from the pharynx to the body wall, contract. This enlarges the pharynx, and the resulting suction aids in drawing the food through the mouth and into the pharynx. The ingested material passes through the pharynx and oesophagus. At the posterior end of the latter a secretion, consisting largely of calcium carbonate, is added to the food, which probably aids in neutralizing any acid condition which may be present. The ma-

terial passes next into the crop, which serves only as a temporary storage place, and then into the muscular gizzard, where it is ground. Finally, the ingested material is passed into the tubular intestine, and, as it moves slowly through this part of the alimentary canal, the endoderm cells carry on the digestive and absorptive processes.

2. *Vascular System*

In the Earthworm, a specialized circulatory system, which has as its function the transportation of various kinds of material to all regions of the body, is present. Such a system forms a necessary part of the structure of all the higher forms of animals. It consists of (1) a circulating medium, the BLOOD, which is adapted for transporting the various materials, and composed of a fluid portion, the PLASMA, containing an enormous number of isolated living cells, the BLOOD CORPUSCLES. (2) The blood is contained in a system of connected, closed, muscular-walled tubes, the BLOOD VESSELS. (3) Specialized portions of the blood vessels, HEARTS, drive the blood through the vessels by means of rhythmical, muscular contractions. There is also present in such types of circulatory systems, (4) a series of LYMPH SPACES permeating the tissues, by means of which the fluid portion of the blood can come into close contact with the living cells of the tissues.

In the circulatory system of the Earthworm, there are two main blood vessels running lengthwise of the body. The larger of these is the DORSAL BLOOD VESSEL which lies on the dorsal side of the alimentary canal (W. f. 66, *C*: *d. v.*). Ventral to the alimentary canal, in the same relative position, is the VENTRAL BLOOD VESSEL (W. f. 66, *C*: *s. i.*). These two vessels are directly connected by five pairs of comparatively heavy-walled, contractile hearts, known as the AORTIC LOOPS, which lie in the anterior end of the body between segments 8 and 14 (W. f. 66, *C*: *a*; 67, *19*, *20*). Three other longitudinal vessels occur in the Earthworm. These are smaller

than the dorsal and ventral vessels, and lie near the ventral body wall in close contact with the ventral nerve cord; one vessel, the SUB-NEURAL, lying below the nerve cord and the other two vessels, the LATERAL-NEURALS, situated one to the right and the other to the left of the nerve cord. (W. f. 67, *23*.)

In each segment of the Earthworm, paired branches are given off from the longitudinal vessels. These run to the various organs and to the body wall, dividing into very fine branches, or capillaries, among the tissues. The principal segmental vessels are:

(1) The PARIETAL VESSELS, a pair of which are given off in each segment by the dorsal blood vessel. They run along the septa and out to the body wall, giving off branches to the tissues of the body wall, and also to the paired, segmental excretory organs, the NEPHRIDIA, before ultimately connecting with the sub-neural vessel (W. f. 67, *18*).

(2) The INTESTINAL VESSELS, two or three pairs of which are given off in each segment from the dorsal vessel, which run directly into tissues of the alimentary canal, where they break up into capillaries. These capillaries in turn connect with capillaries leading to branches of the ventral vessel.

(3) SEGMENTAL BRANCHES are given off by the ventral vessel which run into the alimentary canal, to the body wall, and to the nephridia, where they connect with the branches running to the dorsal vessel (W. f. 66, *C: c. v.*).

The general course of the circulation of the blood in an Earthworm is as follows: Starting at the posterior end of the body, the blood moves forward in the dorsal vessel. The movement is due to rhythmic waves of contraction, or PERISTALSIS, in the muscular walls of the dorsal vessel, which begin at the posterior end of the vessel and move anteriorly in a regular manner. The paired, segmental vessels, mentioned above, empty blood into the dorsal vessel, which is then forced forward as a result of the peristaltic action. At the anterior end of the body a large proportion of the blood flows into the aortic loops. These vessels contract rhythmi-

cally and the blood is forced into the ventral vessel. Valves are present in the aortic loops, which prevent a back-flow into the dorsal vessel.

The general movement of the blood in the ventral vessel is posterior, although a small amount in the region of the aortic loops is forced to the extreme anterior end of the body. The ventral vessel is not contractile, and the posterior flow of blood in it is due to the contractions of the aortic loops. As the blood moves posteriorly in the ventral vessel it is forced out into the segmental branches leading to the body wall, alimentary canal, and nephridia.

Most of the blood from the body wall passes through paired segmental branches to the lateral-neural vessels, and from them to the sub-neural vessel. From the sub-neural vessel, the blood flows into the parietal vessels which, after receiving branches from the nephridia and the body wall, open into the dorsal vessel. The blood from the intestine passes through the paired, segmental vessels into the dorsal vessel and thus completes the circuit.

In the above description of the circulatory system, emphasis has been placed upon the various closed vessels. As a matter of fact, if the circulatory system consisted only of the closed tubes, it would fail to function in supplying the needs of the cells. So all through the tissues there are lymph spaces. The plasma of the blood, with some of the corpuscles, is able to ooze through the thin walls of the capillaries into these lymph spaces, and there the lymph, as this portion of the blood is called, actually comes into contact with, and bathes, the cells. In this way the interchange of all materials between the blood and the cells takes place. The exuded lymph later finds its way back into the regular circulation, after having supplied nourishment to the cells and collected the wastes.

In addition to the circulation of blood by means of the regular vascular system, the Earthworm has an open type of circulation in the coelom. The latter contains the coe-

lomic fluid, which is closely related to the blood in the vessels both in composition and functions. The various movements of the worm bring about contractions of the body, with the result that the coelomic fluid is driven back and forth in an irregular manner through openings in the septa, thus bathing the tissues with which it comes into contact (W. p. 162).

3. *Respiratory System*

The blood carries to the cells not only the food absorbed from the intestine, but also oxygen which, as we know, is absolutely necessary for the metabolic activities. Also the blood carries the metabolic wastes, both liquid and gaseous, away from the cells to the proper excretory organs. The gaseous interchange of carbon dioxide for oxygen occurs in the Earthworm at the surface of the body. The body wall, which is normally kept moist by the secreted mucus, is also richly supplied with the blood vessels, and the blood passing into the body wall comes into close contact with the oxygen of the external environment. (W. pp. 168–169.)

4. *Excretory System*

The Earthworm has a highly developed system for the excretion of the liquid wastes of the body. The system consists of numerous tiny coiled tubes, known as NEPHRIDIA (singular NEPHRIDIUM). Except in the first three or four segments there are two nephridia present in each segment of the body. They lie in the coelom, below the alimentary canal, and close to the ventral body wall, through which they open. In each segment one nephridium lies to the right and one to the left of the median ventral nerve cord (W. fs. 66, *C*: *n*; 67, *25*, *26*).

Each nephridium consists of the following parts: (1) An enlarged, funnel-like, ciliated opening, the NEPHROSTOME; (2) a long, greatly coiled tube which lies in three folds and

consists of (3) a narrow, thin-walled intracellular portion leading from the nephrestome, and (4) a glandular portion, covered with a network of capillaries, which leads to the external opening through the ventral body wall (W. f. 68, *neph*). A nephridium does not lie entirely in one segment, but the nephrostome and a small portion of the connecting tubule penetrate the posterior septum of the segment just in front (W. f. 96).

The nephridia receive the liquid body wastes by two methods. In the first place, certain wastes present in the coelomic fluid are drawn directly into the nephridial tubes by the action of the cilia present in the nephrostomes (W. f. 96, *a*). The body wastes, which have been collected by the blood from other parts of the body, are brought to the glandular portion of the nephridial tubes (W. f. 96, *c*). The cells there present are able to take the wastes from the blood and pass them into the nephridial tubes, from which they are conveyed to the exterior through the nephridial openings in the ventral body wall (W. f. 96, *b*).

5. *Nervous System*

The Earthworm possesses a well-developed nervous system consisting, as in the higher animals, of the CENTRAL NERVOUS SYSTEM and the PERIPHERAL NERVOUS SYSTEM. The former consists of a ventral nerve cord, which lies in a median line in the coelom, ventral to the alimentary canal. It begins at the extreme anterior end of the animal and continues throughout its entire length, enlarging in each segment to form a GANGLION (W. fs. 66, *C: v. g.*; 67, *29*). In the third segment, just under the anterior end of the pharynx, the nerve cord divides to form a collar, composed of the CIRCUM-PHARYNGEAL CONNECTIVES, which completely encircles the pharynx. On the dorsal side of this collar, lying above the pharynx, is a bilobed swelling which constitutes the CEREBRAL GANGLION. This may be regarded as the BRAIN of the

animal. Running forward from the cerebral ganglion are a number of nerve fibers which innervate the extreme anterior end of the body. (W. fs. 66, *C : c.g.*; 67, *27*; 73.)

The peripheral nervous system consists of the small nerves which are given off from the central nervous system in each segment and which innervate the various parts of the body. There is a definite arrangement of these peripheral nerves in each segment as follows: (1) Just back of the anterior septum in each segment a pair of nerves is given off, one of the pair penetrates the body wall on the right side of the body and the other occupies a corresponding position on the left side of the body; (2) from each of the segmental ganglia of the ventral nerve cord two pairs of nerves arise, two of which run to the right side of the body and two to the left; (3) the extreme anterior segmental ganglion, located in the fourth segment just posterior to where the nerve cord divides, is known as the SUBOESOPHAGEAL GANGLION, and from this ganglion several pairs of nerves are given off which aid in innervating the anterior end of the animal. The nerves running anteriorly from the cerebral ganglion are also a part of the peripheral nervous system. (W. fs. 67: *27*, *28*; 73.)

A microscopical examination of a transverse section of the ventral nerve cord in the region of a segmental ganglion shows the following arrangement of tissues: The ganglion is enclosed in a sheath of non-nervous tissue, composed on the outside of a layer of epithelial cells similar to those which cover various other organs in the coelom. Below this epithelial layer is a second layer of the sheath, consisting largely of connective tissue, but containing numerous muscle fibers and blood vessels; the principal blood vessels being the two lateral-neural vessels, one of which lies on either side of the cord, and the sub-neural vessel lying underneath. Embedded in the dorsal part of the inner sheath layer are three longitudinal, rod-like fibrous structures, known as the GIANT FIBERS. The middle one of the giant fibers is much larger than the other two, which lie laterally. The giant fibers run the entire

length of the ventral nerve cord and have a supporting, and possibly also a nervous, function. (W. f. 68, *n. co.*)

The nerve tissue in a ganglion is quite clearly divided into right and left halves, and thus it is apparent that the ventral nerve cord, which appears externally as a single cord, is in reality double, with the two halves fused together. The double nature of the ventral cord is clearly seen in some related forms in which two distinct ventral cords are present. Two types of nervous tissue may be noted in a ganglion. There are, in the first place, numerous nerve cells, or NEURONS, especially in the ventral portion of each ganglion, in each of which the cell body is extended to form a long cell process (W. f. 102). In the second place, the main portion of a ganglion is composed of a mass of nerve fibers, each of which has its origin in a neuron. In other words, the processes of the neurons grow out to a considerable length, thus forming the nerve fibers. The latter constitute the fibrous material of the ganglia and also form the peripheral nerves which are given off from the nerve cord.

PHYSIOLOGY. Experimental studies on the nerve cells of the Earthworm and other animals show that from the functional standpoint there are two types, known as the MOTOR, or EFFERENT, and the SENSORY, or AFFERENT. The motor nerve cells are situated chiefly in the ventral nerve cord, while the sensory nerve cells are situated in the outlying portions of the body, where they are in a position to receive various kinds of stimuli from the environment. The peripheral nerves running from the ventral nerve cord contain both sensory and motor nerve fibers, the sensory fibers running into the ventral nerve cord from the outlying sensory cells, and the motor fibers running from the ventral nerve cord out to all parts of the body, where they connect with the muscle cells (W. f. 101).

It is through this differentiation of the nerve cells that it is possible to bring about coördinated action in response to a stimulus. For example, if the skin of a living Earthworm

is touched with a sharp-pointed instrument, there will be an immediate, coördinated muscular response. In such a case the sensory cells in the skin receive the stimulus from the instrument (W. f. 101, *sc*). The nerve impulse goes from them over the sensory fibers to the ventral nerve cord. Here the message is transferred to the particular motor nerve cells which connect, by their motor nerve fibers, with the muscles in the affected region (W. f. 101, *mc*, *mf*). The muscles then contract in accordance with the stimulus, which was received first by the sensory cells. Such a circuit is known as a REFLEX ARC, and the resulting action as a REFLEX ACTION.

6. *Reproductive System*

The Earthworm possesses permanent organs for sexual reproduction, and since each worm possesses both male and female organs, it is an hermaphroditic animal just as is Hydra. The reproductive organs in the Earthworm, however, are much more highly developed. In the first place, they are permanent organs, and, in the second place, the reproductive system of the Earthworm is greatly complicated by the presence of an elaborate arrangement of accessory structures so that sperm from the animals may be exchanged in order to bring about cross-fertilization; that is, the fertilization of the eggs of one animal by the sperm from another. (W. pp. 203–205.)

MALE ORGANS OF REPRODUCTION. These consist of: (1) Two pairs of TESTES situated in segments 10 and 11. The testes constitute the essential part of the male organs of reproduction, for it is in them that the male sex cells, the sperm, are formed. They are enclosed by the seminal vesicles, noted below.

(2) TWO SPERM DUCTS which open, one to the right and one to the left, on the ventral surface of segment 15. From the external opening each of these sperm ducts continues forward internally to segment 12, where they divide; one branch of

each running to segment 11, and one to segment 10. In these segments the sperm ducts end in ciliated, funnel-shaped openings which are adapted for drawing the sperm into the ducts, from which they are passed to the exterior.

(3) There are three pairs of SEMINAL VESICLES present in segments 9 to 12. Those present in segments 10 and 11 actually enclose the testes, noted above, and the funnels of the sperm ducts. Those present in segments 9 and 12 are attached to the septa and open into the enclosed portions in segments 10 and 11. The sperm are formed only in the testes, but, before they are entirely matured, are set free from the testes into the enclosing seminal vesicles. Here they undergo final development, and are then stored until the proper time, when they pass into the funnel-shaped openings of the sperm ducts and thence to the exterior at the posterior openings of these ducts in segment 15. (W. f. 67, *30–32*.)

(4) Finally, the Earthworm possesses two pairs of SEMINAL RECEPTACLES attached laterally and close to the posterior septum of segments 9 and 10. These open directly to the exterior through the ventral body wall in the grooves between segments 9 and 10, and 10 and 11 (W. f. 67, *33*, *34*). The seminal receptacles remain empty most of the year, but at the breeding season, when the worms pair, they are filled with sperm received from another worm, and it is this foreign sperm that is used to fertilize the eggs.

FEMALE ORGANS OF REPRODUCTION. These are simpler in structure than the male organs, and consist of a single pair of OVARIES situated in segments 13 and 14, one to the right and one to the left of the ventral nerve cord (W. f. 67, *35*). The eggs which develop in them are set free directly into the cavity of the coelom of the 13th segment. They are later carried to the exterior by a pair of OVIDUCTS. The external opening of each oviduct is through the ventral body wall of segment 14. From this point they run forward through the anterior septum of segment 14 into the coelomic cavity of segment 13. Each oviduct begins as an enlarged, ciliated,

funnel-shaped opening situated near to the ovary of that side, and the eggs, which have been freed from the ovaries, are drawn through these openings into the oviducts and then carried to the exterior later. They may remain for a time in an enlarged posterior portion of the oviduct, known as the UTERUS. (W. f. 67, *36*.)

The CLITELLUM, which has been mentioned earlier, is a differentiated glandular structure present in the body wall, normally situated between segments 28 and 35. It serves as an accessory organ during reproduction by the secretion of a band of mucus entirely around the animal, which later hardens and forms a case in which the embryos develop. There are also glands in the ventral body wall of segments 7 to 19, which secrete a sticky material at the time of pairing, and this holds the anterior ends of the animals close together while sperm is being exchanged.

PHYSIOLOGY. The breeding season of the Earthworm usually begins early in the spring. At this time the seminal vesicles of each worm are well filled with mature sperm which have been developing since the previous reproductive period. At the proper time, two worms come together and lie in contact, with their anterior ends pointing in opposite directions, the openings of the sperm ducts on the ventral surface of segment 15 of each worm being directly in contact with the openings of the seminal receptacles on segments 9 to 11 of the other worm. The glands in the ventral body wall of each worm now become active and a coating is formed covering the anterior ends of the two animals. This hardens somewhat, and thus they are held securely together. In this position the sperm from the seminal vesicles of each worm passes down the sperm ducts, out through the openings in segment 15, and into the seminal receptacles of the other worm through the openings in segments 9 to 11. After the exchange of sperm the worms separate.

In each animal the clitellum now becomes active and secretes a mucous band which hardens. The mucous band

is then moved forward by the contractions of the body wall. When it reaches the openings of the oviducts on segment 14, eggs are forced out into it. The ring then continues to move forward, and at segments 9 to 11 receives some of the sperm from the seminal receptacles, which were placed there by the other animal. The band, now containing eggs and sperm, continues to move forward, and, finally, after passing entirely from the animal, contracts to form a small rounded case, or COCOON, in which the eggs, cross-fertilized by the sperm of another animal, develop (W. pp. 125–129).

After fertilization the eggs begin to divide. The cleavage of the egg of an Earthworm is somewhat unequal and irregular, but there is soon formed, just as in the development of Hydra, a hollow sphere, the blastula, and then a two-layered gastrula, the wall of which is composed of an outer ectoderm layer and an inner endoderm layer. Soon mesoderm is formed between the ectoderm and endoderm, and it is within the mesoderm that the coelom arises, which is so important a structural feature of the Earthworm and the higher forms of animals. (W. fs. 69; 115, D.)

ASEXUAL REPRODUCTION BY REGENERATION. In the Earthworm, the normal method of reproduction is sexual, as has just been described. This animal, however, shows great powers of regeneration which, under certain conditions, may amount to asexual reproduction. For example, if an Earthworm is cut into two, or even more, transverse pieces, each piece will develop into a complete worm as a result of the regeneration of the lost parts. Under such circumstances regeneration, just as in Hydra (p. 107) and other lower forms, is essentially asexual reproduction (W. f. 121).

XVIII. CRAYFISH [1]

THE Crayfish is a common example of a large phylum of segmented Invertebrates, known as the Arthropoda. The animals in this phylum are generally regarded as closely related to the Annelida; both groups possessing segmented, triploblastic, bilaterally symmetrical bodies with a ventral nerve cord (W. f. 70). The Arthropoda are, however, more highly organized than the Annelida. This fact is shown to particular advantage in the jointed appendages which all the Arthropoda possess, and in their segmental arrangement. The number of segments in any species of the Arthropoda is definite and limited, and they show a considerable degree of fusion and specialization, particularly in the anterior part of the body, whereas, in the Earthworm, the segments have practically no variation. Attached to almost all of the segments of the Crayfish are jointed appendages. These are structurally modified in the various regions of the body so that they can be used for a number of specific purposes. The appendages are believed to have evolved from a common ancestral type, and are, therefore, examples of HOMOLOGOUS structures. The coelom of the Arthropoda is greatly reduced, and, in fact in the adult animal, it is almost entirely absent. The organ systems of the Arthropoda show, in general, a higher development than the corresponding systems present in the Annelida.

A. THE EXTERNAL STRUCTURE

The Crayfish has an elongated body, generally about six inches in length when fully extended (W. f. 71). The entire body is covered by a heavy, secreted covering (EXOSKELE-

[1] Woodruff, pp. 129–135.

TON). In the anterior portion of the body (CEPHALOTHORAX) the exoskeleton is unsegmented, and is termed the CARAPACE (W. f. 71, *1*). The latter ends in a dorsal projection (ROSTRUM) (W. f. 71, *3*). The ABDOMEN, which makes up the posterior part of the body, is definitely segmented (W. f. 71, *2*). The Crayfish's body comprises a total of twenty-one segments. Of these, six segments (I–VI) constitute the head, eight segments (VII–XIV) constitute the thorax, and seven segments (XV–XXI) the abdomen. The eyes on the first segment are not regarded as appendages by most authorities (W. f. 71, *4*). Also the last segment of the body, the TELSON, does not possess any appendages, thus leaving a total of nineteen pairs of appendages on the body. The exoskeleton, covering each abdominal segment, consists of a curved dorsal portion (TERGUM) connected by a ventral, transverse bar (STERNUM). The ends of the tergum, or PLEURA, project ventrally below the sternum.

B. The Structure of the Appendages

Most of the segments of the abdomen possess a pair of biramous appendages which are attached to the sternum on either side. In the region of the cephalothorax the appendages are variously modified. Posteriorly on the cephalothorax there are five pairs of uniramous walking legs the most anterior pair of which comprises the large pincers (CHELIPEDS) (W. f. 71, *11*). Anterior to the walking legs there are six pairs of mouth parts which are used in the capture, holding, and tearing of the food (W. f. 71, *9, 10*). At the anterior end of the body is a pair of antennae and a pair of antennules (W. f. 71, *5, 6*).

The various appendages of the Crayfish can be divided into two general types:

(1) The BIRAMOUS APPENDAGE, such as is found, in a simple form, on most of the abdominal segments and, in a highly modified form, in the mouth parts. (W. f. 71, *15, 10.*)

A typical biramous abdominal appendage consists of a basal portion, the PROTOPODITE, which is composed of two segments: the COXOPODITE, attached to the body; and the BASIPODITE which bears the two jointed branches, the inner termed the ENDOPODITE and the outer the EXOPODITE (W. f. 72, *10*). This type of appendage is believed to represent the primitive and fundamental type from which the uniramous appendages have been derived (W. pp. 130–133).

(2) The UNIRAMOUS APPENDAGE is represented by the walking legs. In this more simple type of appendage the protopodite shows the same general structure as in the biramous appendage, but the exopodite is always lacking, so that the basipodite bears only one branch, the endopodite. Attached to the coxopodite of certain of the walking legs is a specialized structure, the EPIPODITE, which bears gill filaments (W. f. 72, *8*).

In giving a description of the appendages of the Crayfish, we shall begin with those present on the abdomen, inasmuch as they are more simple and presumably represent, as noted above, the fundamental type.

1. *Abdominal Appendages*

The last appendage on the body is known as the UROPOD, and is attached to segment XX. It consists of an endopodite and exopodite, the latter being divided into two parts. Both are broad, flat plates adapted for swimming (W. f. 72, *11*).

The next four abdominal segments (XVI to XIX) of the female each bears a pair of typical, small biramous appendages, the structure of which has been noted above. The abdominal appendage of segment XV of the female is greatly reduced and not typical. In the male the abdominal appendages of segments XV and XVI are modified for the transference of sperm. The exopodite of each of the typical swimmerets consists of a flattened, blade-like structure made up

of several segments. The endopodite is similar in structure but is somewhat larger. (W. f. 72, *9*, *10*.)

2. *Thoracic Appendages*

There are five pairs of uniramous walking legs attached to segments X to XIV, all of which are built on the same plan (W. f. 72, *8*). The protopodite is made up of the coxopodite and the basipodite. The coxopodite bears the epipodite, with attached gill filaments which project dorsally into the branchial chamber. The epipodite is present on all the walking legs except the last pair on segment XIV. The basipodite bears a five-jointed endopodite, the basal end of the last joint being modified to form a pincer. The pincers of the last four pairs of walking legs are comparatively small, but those of the first pair are very large and strong, and serve as a formidable weapon of defense and offense (W. f. 71, *11*). The exopodite is always lacking.

Segments VII, VIII, and IX each bears a pair of mouth parts, known as the FIRST, SECOND, and THIRD MAXILLIPEDS. Each of these has a basal protopodite, composed of the coxopodite and basipodite, and also a gill-bearing epipodite, noted above. The epipodite of the first maxilliped, however, lacks the gill filaments. The third maxilliped on segment IX is the largest. In this appendage, the exopodite is comparatively short, and consists of a basal portion bearing a jointed, filamentous structure. The endopodite is much larger than the exopodite. It is composed of five joints, the general structure being somewhat like the endopodite of the walking legs, except that a pincer is not present. The first and second maxillipeds are smaller than the third maxilliped, but their structure is much the same (W. f. 72, *6*, *7*). The maxillipeds are more or less covered with hairs, some of which are believed to serve as chemical sense organs and others as tactile sense organs. The maxillipeds aid in holding the food.

3. *Head Appendages*

Segments V and VI each bears a pair of appendages, known as the FIRST and SECOND MAXILLAE. The second maxilla, on segment VI, is one of the most highly modified appendages of the entire body. The protopodite is atypical and is made up of some thin, pliable plates. The exopodite has become greatly modified and, together with the epipodite, forms a broad, flat structure, the SCAPHOGNATHITE, which, by its movements in the branchial chamber, keeps a current of water bathing the gills. The endopodite is a small structure consisting of only one segment (W. f. 72, *5*). The first maxilla, on segment V, is one of the smallest appendages and consists of the protopodite and the endopodite which is a small, atypical structure. The exopodite is entirely lacking (W. f. 72, *4*). Segment IV bears a pair of jaws or MANDIBLES. Each mandible consists chiefly of a protopodite which is made up of two segments, and to which very heavy muscles are attached. The exopodite is lacking and the endopodite is greatly reduced. The mandibles are primarily used for crushing the food (W. f. 72, *3*).

Segments II and III bear a pair of ANTENNAE and ANTENNULES respectively. The antennae on segment III are much larger than the antennules. The protopodite of the antenna is made up of two segments. The proximal segment bears an opening of an excretory organ known as the GREEN GLAND (W. f. 71, *8*). The exopodite of the antennae is a short, thin, blade-like structure, which projects laterally, and the endopodite is a long, many-jointed, whip-like structure (W. f. 71, *6*; f, 72, *2*). The antennules have a protopodite which is made up of three segments, the proximal one of which contains a sensory organ, known as the STATOCYST. The exopodite and the endopodite are practically of the same length and, although somewhat smaller, have the same structure as the endopodites of the antennae (W. f. 71, *5*; f. 72, *1*). The antennules and antennae are primarily

sense organs. Finally, segment I bears a pair of eyes which, however, are generally not regarded as being homologous with the other appendages.

4. *Autotomy and Regeneration of the Appendages*

Many of the Crustacea, including the Crayfish, possess the power of casting off an injured appendage. This is known as AUTOTOMY. There is a definite breaking joint between the second and third segments in the walking legs, and when these appendages are injured, the distal end is definitely broken off. The wound is soon covered over by a membrane of ectoderm cells, and then a process of regeneration begins which soon restores the appendage to the original condition. Autotomy is under the control of the nervous system and is brought about by a series of muscular contractions. In addition to regeneration as a result of autotomy, the Crayfish, particularly when young, possesses regenerative power sufficient to form entire appendages when the original ones are removed. The regenerated appendage, however, does not always have the same structure as the one which was lost.

C. INTERNAL ORGANS

1. *The Alimentary Canal*

The alimentary canal of the Crayfish begins with the mouth, which opens between the mandibles, on the anterior, ventral surface of the third segment (W. f. 71, *17*). Leading dorsally from the mouth is a short, undifferentiated tube, the oesophagus, which opens into the stomach almost directly above the mouth (W. f. 71, *18*). The stomach is a highly specialized organ, and is divided into two parts; an anterior portion (CARDIAC CHAMBER), into the ventral surface of which the oesophagus opens, and a somewhat smaller posterior portion (PYLORIC CHAMBER). In the lining of the

stomach are a number of calcified chitinous structures which together constitute a very complicated food-grinding apparatus, the GASTRIC MILL. The muscle layers in the wall of the stomach are able to move in such a manner as to cause these structures to work against each other and thus to grind up the food. Between the cardiac and pyloric portions is a strainer, made up of filaments, or bristles, and the food must be finely ground in order to pass from the cardiac portion of the stomach into the pyloric (W. f. 71, *19–21*). Leading from the posterior end of the pyloric chamber is a small tube, the INTESTINE, which continues almost straight posteriorly through the center of the abdomen (W. f. 71, *24*). It opens ventrally through the anus in the last segment of the body (W. f. 71, *25*). Large digestive glands, which correspond to those present in higher forms, are located in the thorax, and these produce a secretion which contains the digestive enzymes. The secretion passes into the pyloric chamber of the stomach, through the hepatic ducts. The food of the Crayfish consists both of living and dead animal matter. The process of digestion does not differ fundamentally from that in the Vertebrate animals, and a consideration of it may be left until they are considered.

2. *Vascular System*

The vascular system consists of a number of muscular-walled tubes, the ARTERIES; a pumping organ, the HEART; a series of blood spaces, the SINUSES, distributed through various regions of the body; and, finally, a circulating medium, the BLOOD, which is essentially similar to that of the Earthworm.

The heart of the Crayfish is a highly specialized structure which develops as a dilation of a dorsal blood vessel. The latter occupies a similar position to that found in the Earthworm. The heart lies in the thorax, in a median longitudinal plane, close to the dorsal integument (W. f. 71, *26*).

When the exoskeleton is removed from this region the heart may be seen lying in a chamber, the PERICARDIUM, or PERICARDIAL SINUS (W. f. 71, *27*). Viewed from above the heart shows a somewhat irregular, pentagonal shape. It is kept in position by six strands of fibrous tissue, which originate from the walls of the heart and extend laterally to each side, where they are attached to the walls of the pericardium.

Leading from the heart are the six main arteries which convey the blood to various parts of the body. The arteries may be described as follows:

ANTERIOR MEDIAN ARTERY. This is a single median artery. It leaves the heart at the extreme anterior end, and continues anteriorly, giving off branches which supply the cardiac portion of the stomach, the oesophagus, and portions of the head region (W. f. 71, *29*).

ANTENNARY ARTERIES. A pair of these arise at the anterior end of the heart — one on each side of the median artery. They run anteriorly for a short distance and then ventrally and laterally — one to the right and one to the left. Each of these arteries gives off a branch which runs to the cardiac portion of the stomach, and other branches which supply various organs in the head region, notably the muscles, and the antennae with the green glands.

HEPATIC ARTERIES. A pair of these arise from the anterior end of the heart, just posterior, and ventral, to the antennary arteries. As indicated by their name, they supply the digestive glands.

DORSAL ABDOMINAL ARTERY AND BRANCHES. This large vessel leaves the ventral side of the heart at the extreme posterior end. It runs directly posteriorly through the abdomen, close to the dorsal body wall, and gives off branches which supply the muscle tissue of this region (W. f. 71, *30*). A large branch, the STERNAL ARTERY, arises from the abdominal artery just after it leaves the heart. The sternal artery continues ventrally, at right angles to the abdominal artery, almost to the ventral body wall (W. f. 71, *31*). The ventral

nerve cord of the Crayfish at this point splits into two cords which are united at the segmental ganglia (W. f. 73). The sternal artery passes between the two nerve cords and, underneath them, divides into (*a*) the VENTRAL THORACIC ARTERY, which runs anteriorly under the nerve cord, and (*b*) the VENTRAL ABDOMINAL ARTERY, which runs posteriorly and occupies a corresponding position (W. f. 71, *32*).

The six main arteries of the Crayfish, as just described, all convey blood away from the heart to the various regions of the body. There are six openings (OSTIA) in the muscular walls of the heart through which blood passes into the heart. One pair of these ostia opens through the dorsal wall, one pair through the ventral wall, and one pair opens through the sides. These ostia are provided with simple valves which prevent the outflow of blood (W. f. 71, *28*).

Having considered the heart and the vessels leading from it, we are now in a position to note the structure and position of the blood spaces, or sinuses, which are present in various regions of the body and in which the blood is collected and finally returned to the heart. The pericardial sinus, which surrounds the heart, has already been noted. The main sinus of the body is known as the STERNAL SINUS. It is situated on the ventral side of the body in the region of the thorax. Leading from the sternal sinus are a number of canals, or openings, which lead into the organs for aërating the blood, the GILLS. After passing through the gills the blood passes dorsally into the pericardial sinus. The alimentary canal in the cephalothorax is surrounded by another sinus, known as the PERIVISCERAL SINUS.

The general course of the circulation of the blood is as follows: The blood, which passes into the heart from the surrounding pericardial sinus, through the paired ostia, is forced by the rhythmical contractions of the heavy muscular walls into the various arteries mentioned above. Thus the heart drives the blood both anteriorly (median, antennary, hepatic, and ventral thoracic arteries) and poste-

riorly (dorsal and ventral abdominal arteries). These arteries supply all regions of the body and, in the various tissues, they branch repeatedly and finally form tiny CAPILLARIES. The walls of the latter are of such a character that some of the blood plasma can pass through and come into direct contact with the tissues. In the tissues the blood is gradually collected in various small sinuses, all of which finally open into the large sternal sinus.

The blood, which has come to the sternal sinus from the region of the alimentary canal, carries absorbed food materials, and all the blood there present contains metabolic wastes which have been collected during its passage through the tissues. The next step, therefore, is the passage of the blood from the sternal sinus into and through the gills. These important respiratory organs of the Crayfish are attached, as noted below, either directly by means of the epipodites to certain appendages, or to membranes which are present near the base of the appendages. After passing through the gills, the oxygenated blood flows dorsally through a series of canals (BRANCHIO-CARDIAC CANALS) and then into the pericardial sinus; from which it is drawn into the heart through the ostia, and thus the cycle is completed.

The vascular system of the Crayfish has the same functions to perform as previously noted in the Earthworm, namely, the transportation of various materials through the body.

3. *Respiratory System*

In the Earthworm it was noted that the entire surface of the body acted as a medium through which the blood, plentifully supplied to the body wall, could exchange its waste carbon dioxide for the essential oxygen. In the Crayfish, this process of respiration is carried out by a much more elaborate mechanism, consisting of the branched, filamentous gills, present in the gill chamber of the thorax. The gills in the American genus (*Cambarus*) are attached either

(1) to the coxopodites of the appendages (PODOBRANCHIAE), or (2) to membranes developed at the bases of the appendages (ARTHROBRANCHIAE). In the European genus (*Astacus*) another row of gills (PLEUROBRANCHIAE) is present which are attached to the walls of the thorax. The number of gills varies in different species, but in Cambarus there are 17 gills in the gill chamber on each side of the thorax; six of which are podobranchiae, and eleven of which are arthrobranchiae.

The gill chamber, on either side of the thorax, lies outside of the body wall. It is the space between the outer chitinous exoskeleton and the true body wall of the thorax, dorsal to the attachment of the appendages. A current of water is forced through each gill chamber by the paddle-shaped SCAPHOGNATHITE which, as previously noted, is a part of the second maxilla at the anterior end of the gill chamber (W. f. 72, *5*).

Each gill may be described as a plume-like structure with a central stem, or epipodite, to which a large number of fine filaments, the BRANCHIAE, are attached. Running through the stem and branching into the filaments are two blood vessels; an EFFERENT BRANCHIAL VESSEL which carries blood into the gills from the sternal sinus, and an AFFERENT BRANCHIAL VESSEL which carries blood from the gills. In the gill filaments these vessels lead into tiny, connecting capillaries, and, as the blood passes through these, the gaseous interchange takes place. The gill filaments are very thin-walled and are continually bathed in the water which passes through the gill chamber. The blood, bearing the load of oxygen for the tissues, passes from the gills, through the afferent branchial vessels, and finally reaches the pericardial sinus. (W. pp. 168–169.)

4. *Excretory System*

The excretory organs of the Crayfish, for the elimination of the nitrogenous wastes, are very unusual in their struc-

ture, and not at all similar to the nephridia of the Earthworm. They consist of a pair of small bodies, the GREEN GLANDS, which are situated, as noted, in the posterior part of the head, at the base of each antenna. Each green gland consists of three parts: (1) the GLANDULAR PORTION proper, which takes the wastes from the blood; (2) a thin-walled, sac-like BLADDER, which receives the wastes given off by the glandular portion; and finally, (3) leading from the bladder, a fine tube which opens to the exterior through the wall of the basal segment of each of the antenna. The green glands are vascularized by small branches from the antennary arteries. The blood which they receive passes through the glandular portion of the organ, and the nitrogenous wastes are taken from it. (W. f. 71, *8*.)

5. *The Nervous System*

The nervous system of the Crayfish is fundamentally similar to that which has already been noted in the Earthworm. There is a main VENTRAL NERVE CORD with GANGLIA running the entire length of the body (W. f. 71, *33–35*). This constitutes the CENTRAL NERVOUS SYSTEM, and from it, at the ganglia, peripheral branches are given off which run to all parts of the body. There are, however, certain points of difference between the nervous system of the Crayfish and that of the Earthworm (W. f. 73). These may be summarized as follows:

(1) In the Crayfish, the arrangement of the ganglia in the ventral nerve cord does not correspond to the external segmentation throughout the entire length of the body. This is particularly true in the region of the thorax. Altogether there are 13 ganglia present on the ventral nerve cord, and since there are 21 segments in the body it is apparent that either several ganglia are lacking, or else there has been a consolidation of certain ones. The latter is regarded as the correct explanation, as the facts indicate that a fusion has occurred in certain ganglia of the head and thorax.

(2) In the Crayfish there are a number of specialized SENSE ORGANS present, which are adapted for receiving various kinds of external stimuli, such as tactile, olfactory, auditory, and photic.

The CEREBRAL GANGLION is probably the most important ganglion in the body, and constitutes the brain of the animal. A number of peripheral nerves are given off from this ganglion, which run anteriorly and laterally, and supply the antennules, antennae, and eyes (W. f. 73, *a*). The SUB-OESOPHAGEAL GANGLION gives off a number of nerves which supply the mandibles, maxillae, and the first two pairs of maxillipeds (W. f. 73, *c*). The remainder of the ganglia present in the ventral nerve cord give off branches which, in general, supply the appendages, muscles, and other organs lying near to the region in which they are situated. For the most part the branches arising in all these ganglia, except the cerebral ganglion, are motor in function (W. f. 73, *d*).

SENSE ORGANS. The surface of the body, since it is entirely covered with the hard chitinous exoskeleton, is not provided with numerous sensory nerve cells as is the case in the body of the Earthworm, and the sensory tissue in the Crayfish is largely grouped in the special sense organs situated in the anterior end of the body. These may now be noted.

Tactile Organs. Scattered over the appendages and also in some other regions of the body are found hair-like filaments (SETAE) which are believed to be tactile sense organs. It appears that these setae are each connected with a fine nerve fiber, and anything which comes into contact with them sets up an impulse along the attached nerve.

Olfactory Organs. It is believed that certain jointed filaments, which are present in small groups on the under surface of the exopodite of the antennules, have an olfactory function.

Organs of Hearing or Position. Situated in the basal joint of each antennule is a sac, the STATOCYST, which contains a great number of very fine hairs distributed along two

ridges. A nerve runs into the base of the sac, and branches from it are distributed to these hairs. Among these hairs, grains of sand (STATOLITHS) are commonly found, and these may be attached to the hairs. Although this organ was originally thought to be a sound-receiving organ, experimental work has apparently shown that its real function is that of equilibration, that is, giving the animal a sense of its position. It has been found, for example, that animals from which the statoliths of these organs have been removed are unable to orient themselves and, furthermore, if fine iron filings be supplied to these organs instead of statoliths, the position of an animal can be influenced by the use of a magnet.

Organs of Sight. The Crayfish possesses a pair of eyes which are borne on small stalks, attached just dorsal to the antennae at the anterior end of the head (W. f. 71, *4*). These eyes are very highly developed, and inasmuch as each one is composed of about 2500 units, termed OMMATIDIA, they are known as COMPOUND EYES. Each ommatidium is a complicated, elongated, light-receiving structure which is connected at the base with a branch of a nerve from the cerebral ganglion. When this compound eye is viewed from the front, the surface appears as a mosaic made up of a great number of four-sided areas. Each ommatidium receives light from only a certain restricted area, and the image which the Crayfish receives is believed to be a composite one built up from the separate images which have been received by all the ommatidia.

6. *Reproductive System*

The Crayfish is a dioecious animal, that is, the two sexes are separate. This is different from the condition which has previously been noted in the Hydra and the Earthworm, both of which are hermaphroditic animals.

MALE ORGANS OF REPRODUCTION. The sperm are developed in a single testis, lying near the pericardium. The

anterior portion of the testis is bilobed. The posterior end is single. Leading from the right, and from the left, side of the posterior portion are two ducts (VAS DEFERENS) which open to the exterior through the coxopodites of the fifth walking legs. The testis is largely composed of a mass of fine tubules in the walls of which the sperm are formed. When the sperm have reached the proper stage of maturity, they pass down the tubules and eventually leave the testis through the vas deferens (W. f. 71, *37–39*).

FEMALE ORGANS OF REPRODUCTION. The eggs are developed in a bilobed ovary which is situated in the same general region in the female as is the testis in the male. Leading from the ovary are two tubes (OVIDUCTS), each of which opens to the exterior through the coxopodite of the third walking leg. The ovary of the Crayfish contains a central cavity connected with the oviducts. The eggs are formed from specialized germinal cells located in the wall of this cavity. When ripe they break loose from the wall, into the central cavity from which they are taken to the exterior by the oviducts.

DEVELOPMENT OF THE CRAYFISH. The breeding season of the Crayfish is in the fall. At this time the two sexes pair, and sperm cells are transferred from the male to the female. The sperm remain throughout the winter in a small cavity, the SEMINAL RECEPTACLE, situated on the ventral surface of the body of the female, close to the fourth and fifth walking legs. The following spring, the eggs, which have developed in the ovary, are laid after being fertilized by the sperm stored in the seminal receptacle. The fertilized eggs are attached by a sticky secretion to hairs present on the abdominal appendages of the female. At this time almost the entire ventral surface of the abdomen of the female may be covered with the developing eggs.

When the egg has been fertilized, division begins. However, the entire egg of the Crayfish does not divide at first, but only the synkaryon. The latter divides to form a num-

ber of nuclei which lie in the center of the developing egg. These nuclei later migrate to the periphery of the egg, and then the egg divides radially into as many parts as there are nuclei. Division at right angles later occurs in such a manner as to cut off a small peripheral portion of the cytoplasm, surrounding each nucleus, from each of the radial parts. Thus, at this stage, the egg consists of (1) an outer surface layer of cells which contain the nuclei, and surround (2) an inner mass of yolk material. The latter does not play any further direct part in the development of the embryo, but supplies the necessary food material. The embryo in the Crayfish, therefore, develops on the surface of the egg.

When the young embryo has reached a certain stage of development it hatches, that is to say, it breaks out of the egg capsule which has thus far enclosed it and becomes more or less free. It is, however, still attached to an abdominal appendage of the mother by means of a filament which runs to the embryonic telson. It passes through three successive growth stages (MOULTS), shedding its cuticular exoskeleton each time, before it finally detaches itself from the mother, and thus becomes a free-living Crayfish of small size, but in general appearance like the adult.

XIX. HONEY BEE[1]

THE Insects comprise one of the chief classes of the Arthropoda, and really constitute one of the most remarkable groups in the entire animal kingdom. Numerically, they constitute about four-fifths of all known animals. Structurally, they are one of the most highly specialized groups of animals. Some of them, such as the Bees, Ants, and Wasps, exhibit a complex and highly developed communal life which is only exceeded by that of Man (W. p. 331).

The structure of the body of all Insects shows certain well-defined characteristics. The body is definitely divided into the head, thorax, and abdomen. Three pairs of legs are always present on the thorax, and generally also two pairs of wings. In a typical Insect, the head apparently consists of five or six segments, the thorax of three segments, and the abdomen of ten or eleven segments. There is, however, a considerable variation in the number of abdominal segments in various types of Insects. In the Bee, for example, there are only six visible segments in the abdomen. Insects as a group possess a remarkable and characteristic respiratory system, adapted for air breathing. This system consists of a series of ramifying tubes which carry air containing oxygen directly to the tissues. The Honey Bee, because of its structure, its interesting communal life, and its economic importance, may be taken as an example of the Insects for our present study.

A. External Structure

In an active hive, three types are found which show differences both in their structure and functions. There are

[1] Woodruff, pp. 324–329.

several hundred fertile males, the DRONES; one fertile female, the QUEEN; and several thousand infertile females, the WORKERS (W. f. 175). It will be best to describe first the structure of the Workers and later to note the differences which are present in other types. The body of the Bee, consisting of the head, thorax, and abdomen, is entirely covered over by a cuticle which is formed as a secretion by a layer of cells lying just underneath. This chitinous layer, which is quite rigid, affords considerable protection and support to the animal and it constitutes the exoskeleton. It is homologous with the exoskeleton of the Crayfish.

1. *The Head*

It is generally believed that the head of the Bee is composed of six segments. However, the segmentation even in the embryonic condition is not entirely clear, and in the adult segmental lines are not present. The head bears a pair of large compound eyes, one of which protrudes from either side. They have the same general structure as those of the Crayfish. Also attached to the head are several highly specialized structures which may be summarized as follows (W. f. 176):

(1) A pair of ANTENNAE which are attached to the anterior surface of the head and project forward. They are hairy, jointed structures which, as will be seen later, serve as very important sense organs (W. f. 176, *a*).

(2) The MOUTH PARTS consist, first, of an upper lip, or LABRUM, which is attached to a rounded portion, the CLYPEUS, of the anterior wall of the head lying just below the points of attachment of the antennae.

(3) Below the labrum is an unpaired, fleshy structure, known as the EPIPHARYNX. This is apparently an organ of taste (W. f. 176, *g*).

(4) Next comes a pair of jaws, or MANDIBLES, which are attached, one at either end of the labrum. When closed, the

mandibles lie over the labrum and epipharynx, so that these structures cannot be seen when the head is viewed from the front. When open, they project ventrally and disclose the underlying structures. The latter condition is shown in the figure (W. f. 176, *m*).

(5) Next comes the lower lip (LABIUM, or HYPOPHARYNX), which is a large, median structure attached ventrally to the floor of the mouth by a triangular piece of tissue, the SUBMENTUM. The labium consists essentially of a basal rod (MENTUM) from which projects a long, flexible, jointed tongue (LIGULA) bearing a specialized structure, termed the spoon, or BOUTON, at its tip (W. f. 176, *l*, *b*).

(6) On either side of the tongue is a pair of jointed, elongated organs, known as the LABIAL PALPS (W. f. 176, *lp*). Lying lateral to the labial palps are the lower jaws, or MAXILLAE, and the MAXILLARY PALPS (W. f. 176, *mx*, *mxp*).

The mouth parts of the Bee are adapted for extracting nectar from flowers. They are so constructed that the maxillae and the labial palps, lying on either side of the tongue, can be brought together to form a tube which encloses the tongue, and in which the latter can be moved back and forth. The drops of nectar are first collected on the hairs which cover the tongue. They are then forced upward by the action of the maxillae and labial palps. Finally, the epipharynx can be so placed as to afford a direct passage into the oesophagus.

2. *The Thorax*

The thorax in all Insects consists of three segments, each of which bears a pair of legs. These are known, beginning anteriorly, as the PROTHORACIC, MESOTHORACIC, and METATHORACIC segments. The paired legs are named in accordance with the segment to which they are attached. The mesothoracic and the metathoracic segments each bears a pair of wings in addition to the pair of legs. The wings consist of a membranous, transparent material supported by heavier chitinous structures, known as VEINS. The two

wings on the same side of the body may be united to each other by means of a row of hooks which are present on the anterior margin of the hind wing. The hooks can be inserted in a receptacle on the posterior margin of the anterior wing. When the Bee is flying, the wings are widely extended. When at rest, the wings are drawn close to the body on each side. The wings and the legs are operated by very powerful muscles, which lie in, and largely fill, the thoracic cavity.

STRUCTURE AND FUNCTIONS OF THE LEGS. The three pairs of legs of the Bee are beautifully adapted for the various necessary types of work. They are, indeed, to be ranked among the most remarkable structures that are found in the Insects, or for that matter in any other group of animals. The fundamental structure of the Bee's legs is typical of Insect legs in general. They consist of five joints, or segments, which, beginning with the one attached to the body, are named as follows: COXA, TROCHANTER, FEMUR, TIBIA, and TARSUS; the latter is itself made up of five parts, the first of which is known as the METATARSUS. The joints, the coxa and trochanter are comparatively small and lie close to the body; the femur, tibia, and tarsus, therefore, comprise the major portion of the leg. (W. f. 177, *B*.)

Prothoracic Legs. The femur and tibia are covered with characteristic long BRANCHED HAIRS, a few of which may also be found on the coxa and trochanter. These hairs aid in gathering pollen. On the outer surface of the tibia, just above where it joins with the tarsus, is a stiff brush of curved bristles, known as the POLLEN BRUSH, which is used to brush the loose pollen grains. Attached to the inner side of the tibia nearby is a flattened, movable, chitinous structure, the VELUM, which somewhat resembles in shape the blade of an old-fashioned razor. The velum joins with a crescent-shaped indentation, known as the ANTENNA COMB, on the inner side of the first joint of the tarsus. It contains a number of toothed structures as in a comb. The velum and the antenna comb form the ANTENNA CLEANER. The antennae,

held in place by the velum, can be drawn through the curved antennae comb and cleaned in this way. On the outer edge of the large first joint of the tarsus, there is a row of stiff bristles which project a considerable distance beyond the surface of the leg. These bristles constitute the EYEBRUSH. The latter is used to brush the hairs, which project in considerable numbers from the surface of the large compound eyes, and thus rid them of any foreign particles that may be lodged between them. The next three joints of the tarsus are small and similar in structure. The last joint of the tarsus is so fashioned as to permit the animal to cling to various types of surfaces. Also on this joint of the tarsus, claws are developed laterally which bear tactile, or sensory, hairs. Between the claws is a comparatively large, fleshy structure, known as the PULVILLUS. This structure is glandular, and from it a sticky liquid is secreted which enables the animal to cling to a smooth surface. (W. f. 177, *C*, *E*, *F*, *H*; f. 178.)

Mesothoracic Legs. On the distal end of the tibia, near the joint with the tarsus, there is a long chitinous rod, the POLLEN SPUR. It occupies about the same position as does the velum on the prothoracic legs. This pollen spur is used to dislodge the pollen which has been collected by the animal and stored in the special pollen baskets. The latter occur on the metathoracic leg and are described below. A pollen brush is present. The tarsus of the mesothoracic leg, however, lacks both the antenna comb and the eyebrush. (W. f. 177, *D*.)

Metathoracic Legs. This pair of legs possesses a number of interesting modifications. In the first place, the distribution of the branched filamentous hairs is somewhat different, none at all being found on the tibia as in the other two legs. The tibia is modified to form a large cavity, the POLLEN BASKET, which runs the entire length of the segment. It consists of a long depression on the outer surface, in which the pollen is placed. The pollen is held there by hairs which

arise on the edges of the tibia. The hairs curve over the underlying depression in the tibia in such a way as to hold the pollen grains definitely in position. The distal end of the tibia, where it joins with the tarsus, has a series of spines which constitute the PECTEN. These fit into a special structure, the AURICLE, on the proximal edge of the tarsus. The auricle and the pecten together form the WAX PINCERS. On the inner side of the metatarsus are the pollen combs, which consist of several rows of regularly arranged bristles. The latter are used to comb the pollen out of the branched hairs of the animal and to transfer it to the pollen basket of the opposite metathoracic leg. (W. f. 177, *A*, *B*, *G*.)

3. *The Abdomen*

The abdomen is clearly divided externally into six segments. Each segment consists of an enclosing band of the chitinous exoskeleton which, when seen in a transverse section, shows the same general plan of structure as found in the abdominal segments of the Crayfish, with a dorsal plate, or TERGUM, and a ventral plate, or STERNUM. The separate exoskeletal rings are connected and articulated with each other by soft membranous tissues so that, just as in the Crayfish, a considerable movement may be brought about by the action of the abdominal muscles. The sternum, on each of the four posterior segments, possesses a pair of ventral openings which are connected with the internal wax glands.

At the extreme posterior end of the abdomen, enclosed within the body wall, is a very complex organ for defense, the STING. There is an elongated, chitinous rod, the SHEATH, and a pair of DARTS with saw-teeth edges, one of which lies on either side of the sheath. Laterally, there is a pair of fleshy, hair-covered structures provided with sense organs, the FEELERS. The feelers locate a favorable region on the animal that is being attacked, and then the sheath with the darts is forced down into the tissues at the spot selected.

There are large muscles attached to the proximal end of the sheath structure and also to the abdominal wall, which, by their contraction, bring about the movement of the sheath and darts. When the darts have been forced into the tissues there is an injection through them of poisonous material. The latter is formed in a convoluted, tubular structure, the POISON GLANDS, which secrete the poison into an enlarged portion of the tube, known as the POISON SAC. From the sac a tube leads down along the sheath. The poison is composed of an acid and an alkali, and there is a definite region in the poison glands for the secretion of each of these two substances. It is stated that it is generally fatal for the Bee to use the sting, for, when the darts and the sheath have been forced into the tissues of the other animal, it is very rarely that they can be dislodged without tearing off the posterior end of the abdomen.

The external structure of the Worker, as noted above, is somewhat different from that found in either the Drone or the Queen. The body of the Drone is noticeably larger than that of the Worker, and has a broad, heavy abdomen which lacks a sting. The metathoracic legs lack the pollen basket. The eyes are very large. The body of the Queen resembles that of the Worker in general contour, but it is larger and the abdomen is more elongated. The pollen baskets are lacking (W. f. 175).

B. Internal Organs

The general arrangement of the internal organs of the Honey Bee is fundamentally the same as described in the study of the Crayfish.

1. *Alimentary Canal*

The tubular alimentary canal is differentiated to form a number of interesting structures. The mouth is adapted for the intake of liquid food. The complicated mouth parts, as noted above, form a tube, through which the liquid at

the base of the flower is forced into the mouth. Connecting with the mouth is the oesophagus. This is a small, undifferentiated tube running from the mouth entirely through the thorax and into the anterior end of the abdomen. Here it enlarges to form a unique structure, known as the HONEY SAC. By means of this organ the Bee is able to store temporarily a considerable quantity of nectar for the honey. When the hive is reached, the nectar stored in the honey sac can be regurgitated and placed in the cells to form honey.

At the posterior end of the honey sac there is an opening with four lips, known as the STOMACH-MOUTH. These lips are regulated by special sets of muscles which open and close them when needed. The stomach-mouth leads through a short narrow tube into the stomach. The latter is quite large and has heavy muscular walls, with both longitudinal and circular layers. The stomach is lined with a layer of cells which secrete the digestive enzymes. Other cells in this lining layer are absorptive, and a certain amount of the digested food is absorbed from the stomach by them and passed into the blood stream. The unabsorbed, partially digested food passes from the stomach into the small intestine. This organ is much smaller in diameter, but the walls have the same general structure as those of the stomach. Here the remainder of the food is digested and absorbed into the blood. The small intestine enlarges posteriorly to form the COLON. The latter merges into the RECTUM, which opens to the exterior on the last abdominal segment.

2. *Respiratory and Vascular Systems*

The respiratory organs of the Bee consist, as previously noted, of a complex system of thin-walled air tubes, or TRACHEAE, which ramify through the body tissues. These tracheal tubes open to the exterior through seven pairs of definite openings, or SPIRACLES, which are situated on the right and left sides of a number of the thoracic and abdominal segments. There is one pair of spiracles on both the

prothoracic segment and the metathoracic segment, and five pairs are present on the abdominal segments. The spiracles open inside the body into the LONGITUDINAL TRACHEAL TRUNKS which extend along either side of the body, and from which the finer ramifying tracheae arise. In the anterior end of the abdomen, the tracheal trunks are very large and constitute definite air sacs, which, when filled with air, are supposed to aid the Bee in flight by lowering the specific gravity of the animal. There is a definite expansion and contraction of these air sacs, possibly corresponding somewhat to the breathing movements of the higher Vertebrate animals.

This respiratory system of Insects is very efficient. The air, containing oxygen, comes into direct contact with the body tissues. There is, therefore, no need of a supplementary system to transport the oxygen, such as is found in the circulatory systems of other animals. As might be expected from this, the vascular system does not show as high a development as in some lower forms. It is sufficiently developed in the Bee, however, to transport the absorbed food material from the intestines to the various parts of the body, and also to collect the liquid nitrogenous wastes and carry them to the excretory organs.

The main blood vessel in the Bee is the DORSAL BLOOD VESSEL. This vessel extends almost the length of the body in a median line just below the dorsal body wall. The posterior part of this vessel, lying in the abdomen, is differentiated to form the heart. The latter consists of a linear series of five muscular compartments, known as the VENTRICLES, each of which possesses a pair of openings, the OSTIA. The heart lies in a PERICARDIAL SINUS, and the general relations between these structures are similar to that observed in the Crayfish. The dorsal vessel, of which the heart is a modified portion, continues posteriorly a short distance from the heart and finally ends blindly in the abdomen. Anteriorly this vessel passes into the head region, where it gives off a number of branches.

The course of the circulation of the blood is as follows: The blood, which has been received in the pericardial sinus, passes into the ventricles of the heart through the paired ostia. By the contraction of the ventricles the greater part of the blood is driven anteriorly through the dorsal vessel. It passes from the latter into various sinuses which eventually lead it to the ventral part of the body, from whence it is conducted back into the pericardial sinus. The circulating fluid is typical of that found in many of the Arthropoda.

3. *Excretory System*

The excretory system of the Bee and of Insects in general is different from that of most other animals. It consists of a considerable number of long filamentous tubules, all of which open into the intestine near its anterior end. These are known as the MALPIGHIAN TUBULES. The walls of these tubes are highly vascularized and contain specialized cells which are able to take the liquid metabolic waste products from the blood. These liquid excreta, instead of leaving the body in a liquid form by separate ducts, are passed into the intestine. The latter organ, therefore, serves not only as an organ of egestion for the elimination of indigestible materials, but also as an organ for the excretion of metabolic wastes.

4. *Nervous System*

The nervous system shows a great similarity to that of the Crayfish. However, the double nature of the ventral nerve cord is more clearly shown in the Bee. Altogether there are nine paired ganglia present in the nerve cord. Of these two are located in the head, two in the thorax, and five in the abdomen. The first, or cerebral, ganglion constitutes the brain of the Bee. It is situated in the head above the oesophagus. Various branches are given off from it which run to the sensory organs of the head. Lying in the head, below the oesophagus, is the suboesophageal ganglion, which is also well developed. The nerves of this ganglion innervate a number of the mouth parts. Of the two thoracic ganglia,

the posterior one is much the larger and, as in the Crayfish, undoubtedly consists of a number of fused ganglia. This large posterior thoracic ganglion gives off nerves which innervate both pairs of wings, and also the mesothoracic and metathoracic legs. The prothoracic legs are innervated by nerves from the anterior thoracic ganglion. Of the five abdominal ganglia, the posterior one is the largest. Branches from it innervate the genital organs and the sting. The other four ganglia of the abdomen give off nerves which supply various other abdominal organs.

In addition to the ganglionated ventral nerve cord, as just described, there is also present, in each segment of the body, a triangular-shaped nerve ganglion from which nerve fibers are given off. These ganglia are connected by a common nerve cord, and the entire structure is regarded as being similar in function to the autonomic nervous system of the higher animals. There are also a number of small ganglia present in various regions of the body, which innervate certain parts of the alimentary canal, the vascular, and respiratory systems.

SENSE ORGANS. The Bee possesses a number of sense organs which are of a high type and capable of receiving various types of stimuli from the environment.

Tactile Organs. For the sense of touch, the Bee possesses hair-like structures situated on various parts of the body, but particularly on the antennae. There are apparently two types of these structures: large ones, known as CONOID HAIRS, each of which projects through the wall of the antennae. The conoid hairs each contain a central cavity with a fine nerve fiber. The other tactile hairs are smaller, but otherwise they are essentially the same.

Organs of Taste and Smell. The sense of taste is located apparently in certain cavities situated in the epipharynx, and also in the tongue near its distal end. Each of these depressions is connected with the central nervous system by a nerve fiber which ends in a specialized area at the base of

the cavity. The sense of smell is believed to be located in certain other cavities which, together with the tactile organs, are situated on the antennae. It is stated that the Worker possesses about 2400, the Queen about 1600, and the Drone about 38,000 of these olfactory organs on each antenna. The organs of taste and smell, as just described, are very similar in structure, and it is difficult to draw a clear distinction between them.

Auditory Organs. The auditory organs of the Bee are located in certain specialized cavities also present in the antennae. At the bottom of each of these is a cone-shaped structure with a nerve cell connection. It is still a question as to whether these are really organs of hearing or whether they play some other function in the life of the organism.

Organs of Sight. The Bee possesses two large compound eyes, one on either side of the head, and three simple eyes, or OCELLI, which are situated on the dorsal wall of the head, close to the median line. The compound eyes are similar in structure to those found in other Arthropoda. Each eye is made up of about five thousand ommatidia. Projecting from the surface of the compound eyes, and arising from between the ommatidia, are a great number of hairs which apparently are protective in function. Pollen grains, and other débris, which lodge between the hairs are removed by the eye-brush on the prothoracic legs, the structure of which has already been noted. The ocelli are regarded as simple eyes because each consists of a single unit. Each ocellus can be regarded as similar in function to a single ommatidium of the compound eye. The ocelli are innervated by branches from the cerebral ganglion. (W. f. 176.)

5. *Reproductive System*

MALE REPRODUCTIVE ORGANS. The male reproductive organs of the Drones consist essentially of a pair of TESTES. These organs are made up of a great number of fine, coiled tubes, the SPERMATIC TUBULES, in which the sperm develop.

In a testis, the spermatic tubules all connect at one end with a much larger coiled duct, known as the VAS DEFERENS, and this in turn empties into a still larger uncoiled portion, the SEMINAL VESICLE. Each seminal vesicle opens into a glandular structure, designated as the ACCESSORY GLAND. The gland from each side unites, and from this region the common EJACULATORY DUCT arises which opens to the exterior through the COPULATORY ORGAN. The mature sperm, after passing from the testis through the vas deferens, may be stored for a time in the seminal vesicles, but eventually they pass on into the accessory gland, where they are mixed with a secreted fluid. They are then ready to be passed out of the body of the male, and transferred by the copulatory organ of the latter to a cavity, termed the SPERMATHECA, in the Queen.

FEMALE REPRODUCTIVE ORGANS. Fully developed female reproductive organs are found only in the Queen. The essential organs are a pair of large OVARIES in which the eggs develop. The ovaries fill a large part of the abdominal cavity. They contain eggs in various stages of development, the general arrangement being such that the most mature eggs are situated toward the posterior end. The eggs are carried away from the ovary by a short straight tube, the OVIDUCT. The oviduct from each side unites to form a common tube, the VAGINA. Opening into the latter is the sac-like SPERMATHECA, which contains sperm received from a male during the nuptial flight. The vagina opens to the exterior at the posterior end of the abdomen, near the sting. It is known that the Queen can lay two kinds of eggs: (1) UNFERTILIZED EGGS, which develop into Drones, and (2) FERTILIZED EGGS, which develop either into another Queen, or into the sexually undeveloped Workers. It is not known how this process is regulated. (W. p. 249.)

DEVELOPMENT OF THE BEE. When a colony of Bees becomes so large that the hive is crowded, a new Queen is developed. Later, when the young Queen has reached sex-

ual maturity, the old Queen leaves the hive, accompanied by considerable numbers of followers. This is known as SWARMING. The swarm eventually finds a suitable place in which to establish a new colony, and a regular routine again begins. Shortly after this the young Queen emerges from the old hive and performs her NUPTIAL FLIGHT during which mating occurs high in the air with one of the Drones. Returning to the old hive, the young Queen is supplied with food by the Workers and becomes practically an egg-laying machine. Each day she lays a considerable number of eggs, most of which are fertilized. The eggs are deposited by the Queen in cells built by the Workers, and there they develop; the fertilized ones into Workers, and the unfertilized into Drones. The early development of the egg of a Bee is similar to that of the Crayfish.

6. *Metamorphosis*

Before finally reaching the adult condition, Insects typically pass through a regular series of developmental stages, a process which is known as METAMORPHOSIS. Two types of metamorphosis may be noted: (1) INCOMPLETE OR DIRECT METAMORPHOSIS, as shown, for example, by the Grasshopper, and (2) COMPLETE METAMORPHOSIS, which occurs, for example, in the Bee. The four stages in the metamorphosis of the Bee are known as the EGG, LARVA, PUPA, and ADULT. They may now be considered in the order named. The eggs, which are laid by the Queen in specially prepared cells, are small, oblong bodies of a rather grayish color. After a few days there develops from each egg an elongated, worm-like organism, the LARVA. The larva is the feeding stage, and during this period the embryos are supplied with a highly nutritious food, known as CHYLE, or BEE-MILK. Chyle is formed by the Workers, and it consists of digested honey and pollen mixed with certain glandular secretions. Certain of the workers serve as nurses for the larvae, and they see to it that the latter are supplied with a plentiful amount of food.

The larval period lasts about five or six days, during which time the young embryo increases a great many times in size. Since the outer covering of a larva is chitinous and rigid, it is necessary that this be shed periodically and replaced with a larger size as growth proceeds. This process, which takes place a number of times while the embryo is in the larval stage, is known as MOULTING. It is of the same character as in the Crayfish.

At the end of the larval period, when a certain size has been reached, each embryo proceeds to spin a COCOON around itself. The cocoon is formed by the secretions of certain specialized SPINNING GLANDS which open near the anterior end of the body. The secretion, which is given off as a liquid, soon hardens, and the young embryo thus encases itself in a silky covering, the cocoon. An embryo in this condition is known as a PUPA, and it is a ‘ resting ’ stage which, in the Bee, lasts about two weeks. No food is eaten during this time, and the embryo inside the cocoon is practically rebuilt. The result is that the elongated worm-like larva is metamorphosed into the adult flying insect. This remarkable process of metamorphosis takes about thirteen days in the Workers and Drones, but considerably less in the Queen. When the metamorphic changes have been completed a substance is secreted by the Insect which dissolves a portion of the cocoon and thus permits it to emerge. In many Insects the adult condition lasts only a short time. It has as its chief function the reproduction of the species.

The process of egg laying and development continues until the hive becomes overcrowded. When this occurs the Workers construct one or more queen-cells, and a fertilized egg is deposited in each by the Queen. It is generally believed that the larva which develops from this egg is fed by the Workers with a much richer type of food than are the other larvae. Apparently as a result of this the embryo, instead of becoming a sexually immature Worker, develops into a sexually mature Queen.

C. Activities of the Workers

Whereas the Queen and the Drones are concerned only with reproduction, there are many essential activities of the colony which are carried on by the Workers. These activities include the building of the honeycomb, the gathering and preparation of pollen for food, the collection of the nectar from the flowers, the manufacture of honey from the nectar, and the general care of the hive. The latter comprises the cleaning, warming, ventilation, and guarding of the hive as well as painting the interior with bee glue which is secured from various plants. It is believed that the Workers also determine when a hive is getting overcrowded. If such occurs, they construct the special queen-cells, noted above, in which a new Queen is developed. In the collection of the various substances from the flowers, the worker Bees incidentally transfer pollen from one plant to another, thereby bringing about cross fertilization which, at least in many cases, is essential for the plants.

We may now discuss some of the activities of the Workers in more detail. When it is desired to form wax for the building of a comb, the Bees eat a great deal of honey and then remain quiet for a time, hanging in great numbers from the top of the hive. The honey, which has been eaten, is digested, and a large part of it is used in the formation of the wax, which is secreted by the wax glands. The wax plates thus formed are removed from the abdomen. The wax is then mixed with saliva and kneaded by the mandibles. When the proper consistency has been attained it is placed in just the right place in the comb which is under construction. The cells which compose a honeycomb are generally six-sided. It is a question as to whether these cells, when first formed by the Bees, are hexagonal or circular. Many authorities believe the latter to be the case, and that the six-sided cell arises as a result of the equal pressure of the surrounding cells.

The cells in a honeycomb are named, in general, according to the use which is made of them. As generally described there are six types of cells, as follows: QUEEN-CELLS, DRONE-CELLS, WORKER-CELLS, HONEY-CELLS, TRANSITION-CELLS, and ATTACHMENT-CELLS. The largest of these are the queen-cells. The drone-cells are the next in size, and the smallest cells of all are the worker-cells. The honey-cells and the worker-cells are practically the same size and both of these types may be used, as well as honey-cells, for storing the honey. The attachment-cells are irregular in shape, and serve to attach the mass of the honeycomb to the sides of the hive.

The Workers collect various substances from the flowers. In the first place, they collect the nectar which is secreted in a liquid form at the base of the flower. This is secured by the long tongue in connection with the tubular mouth parts previously described. It is taken into the body and temporarily stored in the honey sac which forms an enlarged portion of the oesophagus just anterior to the stomach. At the hive it is regurgitated and placed in the honey-cells. These are left uncapped for a time. As a result, a considerable part of the water in the nectar evaporates, leaving a concentrated syrup, which is honey. Each honey cell is later sealed over with a wax cap. The nectar of various flowers is collected. The flavor of the honey manufactured depends upon the flowers from which the nectar was collected. Some of the flowers which supply the nectar for the best honey are those of White Clover, Buckwheat, and Alfalfa.

In addition to the nectar for honey manufacture, the Bees gather great quantities of pollen. This constitutes one of their principal foods. Pollen is rich in nitrogenous materials which are not present in the honey, and it is therefore necessary that the Bees have it as the basis of their food. Another material that is collected from plants of various kinds is bee glue, known as PROPOLIS. This is a gummy, resinous

substance which exudes from many plants. The Bees take it and use it to fill up cracks and to cover the interior of the hive.

There are various matters of sanitation that must be looked after in a hive if it is to be kept in good shape. This is due to the fact that there are so many Bees living in close quarters. Any dead animals or waste material of any kind is removed by Workers which are delegated for that purpose. Fresh air must also be supplied. This is accomplished by certain of the Workers who stay at the entrance of the hive and draw in a current of fresh air by keeping their wings in motion. Other Workers guard the hive and act as sentinels at the entrance.

D. Insects in General

1. *Metamorphosis in Other Insects*

It has been noted above that in some Insects, such as the Grasshopper, the metamorphic changes are 'incomplete.' In such a case the pupal stage is lacking. The larvae, known as nymphs, lack wings, and the reproductive organs are immature. They grow, moult several times, and gradually reach the adult condition.

It is during the larval period of many Insects that great damage is done to vegetation. In general, the eggs of an Insect are laid upon the material best suited for the larvae to feed upon. In many cases, particularly in the Moths, the eggs are attached to the leaves of trees, and when the larvae hatch, they immediately begin to defoliate the tree. If they are present in sufficient numbers, as frequently happens, the tree will be stripped of everything green, and in many cases actually killed. The silky cocoon, spun at the end of the larval period, is an interesting structure, and in the case of one species of Moth, *Bombyx mori*, commonly called the Silk Worm, is a very valuable product from which commercial silk is obtained. This is done by unwind-

ing the silky thread which makes up the cocoon, after having first killed the pupa by placing in boiling water. It is stated that the length of thread that may be unwound from an average cocoon is 1526 feet, or somewhat more than one-fourth of a mile. The larvae of many other species spin silk, but the cocoons are without commercial value either because the silk is not of a good quality or because it cannot be unwound.

2. *Polymorphism in Insects*

In the study of the Bee it has been seen that a certain amount of structural differentiation exists between the Queen and the Workers, both of which are potentially female animals. Such differentiation existing between the different members of the same sex of a species is a type of polymorphism. This phenomenon is shown to the greatest degree in certain species of the Ants, in which forms the polymorphism, just as in the Bee, is exhibited for the most part by the female individuals. Thus there are commonly found in an Ant colony the sexually mature Queen, and a series of sexually immature female animals, such as the large and small Workers, Soldiers, and various intermediate forms. The structure of these forms has become variously modified so that they are better adapted for their particular functions. For example, the mandibles of the Soldier Ants are extremely heavy.

3. *Economic Importance of the Insects*

It would be hard to over-emphasize the economic importance of this remarkable group of animals. There are a number of forms like the Bee and the Silk Worm which contribute materially to man's welfare, but, on the other hand, there are an almost unlimited number of species which are very injurious and destructive in various ways.

It has been estimated that the annual losses in the United States alone, due to the destruction of plant and animal products on the farms by various Insects, amounts to more

than three-quarters of a billion dollars. This astounding total does not include the incalculable losses sustained by the human race as the result of insect-borne diseases. The germs of such diseases are sometimes carried *externally*, attached to various parts of the body as, for example, in the case of the common House-fly, which may spread typhoid, tuberculosis, and other vicious diseases in this manner; or in many cases, the Insect may carry the germs of the disease *internally* and transmit it directly to the victim by injecting it in the body, as, for example, in a certain species of the Mosquito, which transmits Malaria in this manner. (W. pp. 334–338.)

XX. CLAM[1]

THE Mollusca constitute a large, important, and structurally aberrant phylum of Invertebrate animals which includes such well-known forms as the Clams, Oysters, Snails, Slugs, Squids, and Octopi. These animals, although very highly developed, exhibit in their bizarre adult organization very few morphological features by which they can be closely linked to any other group of animals. Also, the differences between various members of the phylum are very great. This fact may be noted when one compares, for example, the structure of the common Clam with that of a free-swimming Squid. All these Molluscs, however, are triploblastic, show no evidence of segmentation in the adult condition, and the coelom is greatly reduced. Bilateral symmetry is present to a greater or less degree. Two features are present in some form or other in all types of Mollusca, namely a muscular structure, known as the FOOT, and a secreted SHELL. (W. p. 415.)

The study of a representative of this group is worth while, not only because of the unique structural features which are there shown, but also because of their importance from the economic standpoint. A great many species of Molluscs, such as the Oyster and Clam, are edible. The shells of some species, such as the fresh water Clam, or Mussel, are used in the pearl button industry, and true pearls are also formed by Molluscs. Altogether the shell-fish industry amounts to many millions of dollars annually.

For our present study, either the common, marine Hard Clam, or QUAHOG (*Venus mercenaria*), or the fresh water Mussel (*Unio* or *Anodonta*) may be used. All these forms are very similar in general structure.

[1] Woodruff, p. 135.

A. External Structure

The Clam is completely enclosed in a secreted shell, composed of calcium carbonate. The shell is made up of a right and left half, each of which is spoken of as a valve. The Clam and other Molluscs, which have two valves, are commonly designated as bivalves, in distinction to other types of Molluscs, like the Snails, in which the shell is single and, therefore, are termed the univalves.

In the Clam, the two valves are hinged together along one edge which is regarded as the dorsal surface of the animal. Definite lines of growth in the form of concentric ridges can be noted on the surface of the shell. These lines radiate from an elevated portion, or beak, of each valve, known as the umbo, which typically points toward the anterior end of the animal. From these lines of growth the size of the animal at various stages during its development can be definitely determined. Holding the Clam with the hinged, or dorsal, side up and with the umbo, or anterior, end pointing away, we are able to orient the animal definitely and designate the right and left valves.

The two valves of the shell are connected inside by two large internal muscles, one of which is situated near the anterior end (anterior adductor muscle) and the other in the same relative position near the posterior end (posterior adductor muscle). These two muscles are very strong and are attached directly to the two valves, so that when they are contracted the valves are drawn tightly together. In opening a Clam, the ventral edge of the shell can be broken slightly with a hammer. A knife can then be inserted between the two valves and the adductor muscles cut. When this is done the valves will spring apart somewhat, owing to the action of certain ligaments in the hinges. The internal organs can then be examined. (W. f. 74, *c*, *k*.)

B. Internal Organs

Both valves of the shell are lined, except at the extreme peripheral edges, by a thin tissue known as the MANTLE. The mantle can be carefully separated from both valves of the shell, detached along the dorsal surface, and thus all the internal organs of the Clam, enclosed within the two folds of the mantle, can be removed from the shell. Or, stated in another way, the internal organs of the Clam may be said to be enclosed by first, a heavy secreted shell, and second, a thin membranous layer of living tissue, the mantle, which lies just within and attached to the shell. The cells of the mantle tissue form the shell as a secretion, and the concentric lines of growth indicate the former positions of the edges of the mantle.

The internal structure of the Clam can be studied to advantage by carefully removing the left valve of the shell, together with the left fold of the mantle. This discloses the internal organs of the body, which consist of the VISCERAL MASS, GILLS, and FOOT. All these lie in the space between the valves of the mantle, termed the MANTLE CAVITY. At the posterior end of the animal, the edges of the mantle form two specialized openings, the VENTRAL SIPHON and the DORSAL SIPHON, through which a current of water passes in and out of the mantle cavity (W. f. 74, *m*, *n*, *o*).

The visceral mass, composed of a number of organs which will be considered in detail later, lies between and somewhat dorsal to a line connecting the prominent anterior and posterior adductor muscles which were cut through in removing the left valve. Ventrally the visceral mass merges into the heavy muscular FOOT. The latter is an organ of locomotion and may be protruded between and beyond the ventral edges of the valves. A pair of GILLS is present on each side of the visceral mass. They are suspended from the dorsal portion and hang down ventrally into the mantle cavity, reaching almost to the edge of the mantle. (W. f. 74, *a*, *p*.)

1. *Alimentary Canal*

The MOUTH OPENING is at the anterior end of the body and lies just posterior to the anterior adductor muscle (W. f. 74, *b*). Surrounding the mouth are two pairs of elongated, ciliated structures, the LABIAL PALPS, which are in close connection with the anterior end of the gills. Leading dorsally from the mouth there is a short OESOPHAGUS which opens into the anterior end of the stomach. The anterior wall of the STOMACH lies against the posterior wall of the anterior adductor muscle. The stomach is a rather large, undifferentiated sac (W. f. 74, *d*). Leading from near the middle of the ventral wall of the stomach is a long, greatly coiled INTESTINE which, after proceeding ventrally and posteriorly down into the region of the foot, makes a number of coils and then turns dorsally and continues this course until it is above the dorsal wall of the stomach. At that point it makes a right angle turn, and runs directly posteriorly until it ends at the ANAL OPENING which lies just a little posterior to the posterior adductor muscle (W. f. 74, *f*, *l*).

The HEART of the Clam lies in a PERICARDIUM situated in the median line, and just below the dorsal body wall (W. f. 74, *g*, *h*, *i*). Strangely enough, the intestine passes into the pericardial cavity, and directly through the heart (W. f. 74, *f*). On either side of the stomach is a digestive gland, or LIVER, which secretes certain digestive fluids that are emptied into the stomach through two definite ducts. The intestine, near the basal portion of the foot, is surrounded by the REPRODUCTIVE GONADS.

Certain phases of the Clam's nutrition are unlike those studied in other animals. In the first place, in the capture of food, the gills, which ordinarily are simply respiratory organs, play a prominent part. A constant current of water is brought into the mantle cavity in which the gills are suspended. This water current is due to the action of cilia on the gills. The current passes into the mantle cavity

through the ventral, or inhalent, siphon, and, after passing through the gills, leaves the body through the dorsal, or exhalent, siphon. As the water passes through the gills, small living organisms and also very small particles of organic material, which may be utilized for food, are strained out from the water. The food particles are then carried by the action of specialized gill cilia to the anterior end of the body, where they come into contact with the ciliated labial palps around the mouth. The cilia of the latter beat in such a manner as to create a current which sweeps the particles into the mouth opening.

The food thus taken into the mouth passes through the oesophagus, into the stomach, and then into the intestine, through the walls of which the digested food materials are absorbed and passed to the circulatory system. The indigestible materials pass on through the intestine and are egested at the posterior anal opening. From here they are carried to the exterior through the exhalent siphon by the action of the outgoing water current.

2. *Vascular System*

The Clam has an efficient vascular system which, although somewhat different in details, consists of the same fundamental parts noted in animals previously studied. Certain features of the vascular system recall those found in the Crayfish. The heart lies in a membranous chamber, the PERICARDIUM, and consists of a large muscular VENTRICLE through which, as previously stated, the intestine runs (W. f. 74, *h*, *i*). The pericardial cavity is regarded as the remains of the greatly reduced coelom which is typical of Molluscs. Leading from the anterior end of the ventricle is the ANTERIOR AORTA, and from the posterior end, the POSTERIOR AORTA. These are the two main arteries of the body and they give off branches which supply all parts of the body. Attached to the ventricle are two thin-walled chambers, the AURICLES, one on the right side and one on the left side

(W. f. 74, *g*). These project ventrally through the pericardium and connect with the EFFERENT BRANCHIAL VESSELS from the gills. The auricles pass the blood which they receive into the ventricle. In the tissues of the body are numerous blood SINUSES similar to those previously noted in the Arthropoda. The main vein of the Clam, the VENA CAVA, lies ventral to the pericardium. The blood from the various regions of the body finally collects in it, and is then passed, first, to the kidneys, and then to the gills.

There is one morphological feature of the Molluscan circulatory system which shows a higher type than any hitherto studied, and that is the presence of auricles in the heart. The blood instead of returning to the pericardial cavity and then being taken directly into the ventricles of the heart through the ostia, as in the Crayfish, is received from the branchial vessels by the auricles which are connected with the ventricle. Therefore, the pericardial cavity of the Clam, although it surrounds the heart, does not function as a receiving organ for the blood.

The general course of circulation of the blood is as follows: Beginning with the ventricle of the heart, the blood is forced either anteriorly or posteriorly through the anterior aorta, or the posterior aorta, respectively. These vessels distribute it to all parts of the body. After passing through the tissues, largely by means of the sinuses, it is finally collected into the large vena cava. This vein is connected directly with the kidneys, so that all the blood from it passes next through these excretory organs. During this passage the liquid metabolic wastes are removed. After passing through the kidneys, the blood reaches the gills by way of the afferent branchial vessels. In the gills the respiratory interchange of carbon dioxide and oxygen takes place. The blood, now freed both from the liquid nitrogenous wastes and the carbon dioxide, and carrying a fresh supply of oxygen, passes through the efferent branchial vessels into the right or left auricle of the heart, and then into the ventricle, from whence it is driven

again over the same course. It should be stated that a small portion of the blood passes from the heart, through a branch of the anterior aorta, into the tissues of the mantle, which also serves as an organ of respiration. This blood after passing through the mantle is returned directly to the heart.

3. *Respiratory System*

The chief respiratory organs of the Clam consist of two pairs of gills which, as we have seen, lie in the mantle cavity on either side of the visceral mass (W. f. 74, *p*). Each gill consists of two ciliated, elongated, perforated sheets of tissue (LAMELLAE), which are separated a short distance from each other by regularly arranged vertical rods, the INTERLAMELLAR JUNCTIONS. The edges of the lamellae, with the exception of the dorsal surface, are united together. Each gill may be compared in its structure, therefore, to a very narrow, elongated bag, the top or dorsal side of which is open. The cavity of the bag is divided by the interlamellar junctions into a number of vertical compartments, the WATER TUBES.

The lamellae of the gills are made up of a large number of definitely arranged parts, the GILL FILAMENTS. These run parallel to the interlamellar junctions and give the gill a distinct dorsoventral striation (W. f. 74, *p*). The filaments are connected by INTERFILAMENTAL JUNCTIONS. Regular openings, the OSTIA, are situated between the gill filaments so that water can pass through them and into the spaces, or water tubes, between the lamellae.

The gill filaments are covered with ciliated epithelial cells, the cilia of which exhibit a coördinated, beating movement. This causes a continual current of water to be drawn into the mantle cavity through the inhalent siphon. The water then passes through the ostia of the gills into the water tubes, thence dorsally into a longitudinal SUPRABRANCHIAL CHAMBER which opens posteriorly into the exhalent siphon. During the passage of the water through the gills, the inter-

change of carbon dioxide from the animal for oxygen in the water takes place through the thin walls of the gills. The cilia on the gills exhibit considerable differentiation both in size and function. The beat of some of them is such as to produce a current of water carrying the food particles toward the labial palps, from which it passes into the mouth.

4. *Excretory System*

The excretory organs of the Clam consist of a pair of KIDNEYS, which lie below the pericardial cavity and extend slightly beyond it posteriorly. The posterior wall of the kidney is in close proximity to the posterior adductor muscle. Each kidney consists of two parts; first, a glandular portion which lies ventrally, and second, a storage portion, or BLADDER, which lies dorsal to the glandular portion and in close contact with the ventral wall of the pericardial cavity. These two portions are separated for a considerable distance by a thin wall of tissue, but posteriorly they are in communication through a small opening. The glandular portion of the kidney opens into the pericardial cavity at the anterior end through a small duct, the RENO-PERICARDIAL APERTURE. The bladder opens also anteriorly through a tiny opening, the RENAL APERTURE. The nitrogenous wastes, collected by each kidney, pass from it at the renal aperture and thence are swept out of the animal with the current of water through the exhalent siphon.

The kidney apparently functions in two ways. In the first place, it is believed that certain wastes, present in the pericardium, can be driven directly into the glandular portion of the kidney by the action of the cilia lining the tube which opens into the pericardial cavity. However, the greater portion of the work of excretion is done by the glandular portion of the kidney in taking the liquid wastes from the blood passing through. It is generally believed that the kidney of the Clam represents a greatly modified type of nephridium such as was noted in the Earthworm. Since the

pericardial cavity of the Clam represents the greatly reduced coelom, we have, therefore, much the same situation as in the Earthworm with the nephridium opening directly into the coelom.

5. *Nervous System*

The nervous system of the Clam is atypical in its structure, and quite unlike any nervous system that has so far been noted. It consists of a number of paired ganglia situated in various regions of the body and connected by nerve cords. In the region just posterior to the anterior adductor muscle is a pair of ganglia, the CEREBRO-PLEURAL GANGLIA, one of which lies on either side of the oesophagus. These ganglia are connected with each other by a nerve cord, the CEREBRAL COMMISSURE, which passes around the oesophagus just before the latter opens into the stomach. Running ventrally and posteriorly from each of these ganglia is a nerve cord, the CEREBRO-PEDAL CONNECTIVE, which connects in the basal portion of the foot with a ganglion, known as the PEDAL GANGLION. This ganglion is really double, but the two parts have become almost completely fused so that, externally, the double nature is not clearly apparent. From each of the cerebro-pleural ganglia there is also another nerve cord, the CEREBRO-VISCERAL CONNECTIVE, which runs posteriorly and connects with the VISCERAL GANGLION situated on the ventral side of the posterior adductor muscle. The visceral ganglion has the same general structure as the pedal ganglion. These three paired ganglia with the connectives as given constitute the main parts of the nervous system of the Clam. Peripheral branches are given off from the various ganglia, which innervate the nearby organs.

SENSE ORGANS. In the Clam the sense organs are not so well-developed as in the Arthropoda. Possibly this is due to the fact that the Clam does not move rapidly, and, therefore, does not have the same need of complex sense organs. It is interesting to note in this connection that in

another class of the Mollusca, which includes a number of free-swimming species like the Squid and the Octopus, highly-developed sense organs, such as eyes, are present. There are, however, in the Clam, two sense organs which should be noted. The first of these is known as the OSPHRADIUM. It consists of a small area of pigmented epithelial cells which covers the visceral ganglion. It is believed that this organ, in some way, is able to determine the purity, possibly the oxygen content, of the water which is drawn into the mantle cavity. If the water which comes in is unsuitable it presumably stimulates the cells of the osphradium, with the result that the animal moves on to a more suitable place. Another sense organ is the STATOCYST. It is situated near the pedal ganglion and consists of a small vesicle, containing a calcareous body. It is probably an organ of equilibration. (W. p. 199.)

6. *Reproductive System*

In most species of Clams the sexes are separate, although a few species are hermaphroditic. The general structure of the male and the female gonads is much the same. They are paired organs, situated in the dorsal portion of the foot. The intestine which runs through this same region of the foot is more or less surrounded by the gonads.

The eggs, produced in the ovaries of the female, pass out through a small opening, known as the GENITAL APERTURE, which lies almost directly ventral to the anterior end of the pericardial cavity and just below the renal aperture. In the fresh-water Mussel the eggs pass next to the gills. The particular portion of the gills which retains these eggs — it varies in different species — is known as a BROOD POUCH, or MARSUPIUM. The sperm of the male, produced in the testes, passes out through a similar opening. The sperm, however, are conveyed entirely away from the body of the male with the current of water passing out through the exhalent siphon. Some of the sperm thus discharged into

the surrounding water are drawn into the female animals by the current of water which is continually taken in through the inhalent siphon. This water, containing the sperm, bathes the gills of the females, and there the sperm come in contact with the attached eggs and fertilization occurs.

The fertilized eggs develop in the gills of the mother, and in some species remain there during the following winter. In all cases the eggs undergo a considerable period of development in the gills, and are then discharged into the water, where they begin their independent existence. The eggs of the Clam, when fertilized, undergo complete segmentation and pass through the various embryonic stages with which we are familiar. In the fresh-water Clam there finally develops a characteristic stage, known as a GLOCHIDIUM, which is adapted for attaching itself to a fish by means of teeth-like structures which are present on the edges of the valves. When a fish comes in contact with the glochidium, the gaping shells snap shut into the fish tissues, and the embryo is thus attached to the body of the fish, where it stays for a time as a parasite. The skin of the fish grows over the glochidium, and it receives nourishment from the fish tissues. Finally, it becomes liberated and takes up its independent existence as a mature Clam.

XXI. FROG[1]

THE animal kingdom is commonly said to be divided into the INVERTEBRATES and the VERTEBRATES. The latter, however, really belong in the very much larger group, or phylum, known as the CHORDATA, which includes all the higher forms of animals possessing a backbone, together with a number of lower types, most of which are scarcely known except to zoölogists (W. pp. 146, 415, 416).

The Chordates as well as all Vertebrates possess the following structural features:

(1) A dorsal supporting axis, the NOTOCHORD, which runs practically the entire length of the body, is present at least during development. Among the different groups of Chordate animals there is considerable variation with regard to the condition of the notochord in the adult.

(2) At some period in their life history all Chordates possess paired lateral openings, situated at the anterior end of the body, which connect the cavity of the pharynx directly with the exterior. These openings are known as GILL SLITS, and when functional permit the water, taken in through the mouth, to pass over the gill filaments, which are developed in the wall of the slits, and then to the exterior. Respiration takes place during this process.

(3) A well-developed, hollow central nerve cord, which lies *dorsal* to the alimentary tract, is present at some stage in all the Chordates. It will be remembered that in the Invertebrates, such as the Earthworm and Crayfish, the central nerve cord is situated *ventral* to the alimentary canal.

[1] Woodruff, pp. 116–118; 135–153.

Included in the phylum Chordata are four subphyla designated as follows:

The Enteropneusta. A small group of marine, worm-like animals, such as *Dolichoglossus*, which are difficult to classify, but which in their embryonic condition possess the features noted above.

The Tunicata. A group of marine animals, commonly known as the Sea-squirts, which are also very atypical in their adult structures, but are placed in this group because of the characteristic chordate structures present during development.

The Cephalochorda. A small group of marine animals among which is included the important form, known as Amphioxus, or the Lancelet. They possess an elongated, fish-like body, are rapid swimmers, and retain the structural features of the Chordates throughout life.

The Vertebrata. This is the highest group of Chordates, and includes all animals having a segmented backbone, or spinal column, which develops around the unsegmented, cartilaginous notochord of the embryo. To this group belong the familiar animal types, such as the Fishes, Amphibia, Reptiles, Birds, and, finally, the Mammals among which Man is included.

As generally recognized, there are seven classes of Vertebrate animals as follows:

Cyclostomata. These include fish-like forms such as the Lampreys. They are cold-blooded, the notochord persists, and the skeleton is cartilaginous. Neither jaws nor lateral fins are developed.

Elasmobranchii. These include the Sharks and Rays. They are also cold-blooded, with a cartilaginous skeleton and partially-persistent notochord, but jaws are present.

Pisces. These include all the higher Fishes, such as the Cod and Trout. They are cold-blooded, the skeleton is ossified, and lateral fins are developed.

Amphibia. These include the Urodela, or tailed Am-

phibians, like the Salamanders; and the Anura, or tailless Amphibians, like the Frogs and Toads. All these animals are cold-blooded and have a naked, slimy skin. They all breathe by gills at an early period of their life, but most of the Amphibia later undergo metamorphosis, and breathe by lungs in the adult condition. Well-developed, five-fingered, or PENTADACTYL, limbs are present in most instances.

REPTILIA. These include such forms as the Lizards, Snakes, Turtles, Crocodiles. They are cold-blooded, scaly-skinned animals, none of which breathe by gills at any period of their life history.

AVES. These include the Birds which constitute a well-defined class of Vertebrate animals. They are all warm-blooded, possess feathers, and have their fore limbs modified for flying.

MAMMALIA. These include the highest Vertebrates, such as the Whales, Seals, Bats, Horses, Dogs, Cats, Monkeys, Man, etc. All these animals are warm-blooded, are more or less covered with hair, and the young are nourished for a time after birth by secretions from the specialized MAMMARY GLANDS of the mother.

A. The External Structure of the Frog

The Frog, although it gives a good general idea of the chief structural features of the Vertebrates, is atypical in some respects. It is possible that better results could be obtained from a study either of a lower Vertebrate, like a Fish, or a higher Vertebrate, such as a Dog or Cat. Since these animals are not so well adapted for work in the laboratory, the Frog will, in general, be utilized as the basis for the present discussion, but in the case of certain organs a description of the condition in Man or some other higher Vertebrate will be given.

The body of the Frog is divided into two regions, the HEAD and TRUNK. The NECK, which is present in higher

Vertebrates, is lacking. Attached to the trunk is a pair of fore limbs and a pair of hind limbs, both of which are well-developed, jointed, pentadactyl appendages. The fore limb is composed of three main parts, commonly known as the UPPER ARM, FOREARM, and HAND. The latter is composed of the wrist and four well-formed digits, together with a very rudimentary first digit, corresponding to our thumb, which can be felt through the skin. The hind limb has the same general structure as the fore limb, but is much larger and more powerful. The various parts of it are commonly spoken of as the THIGH, SHANK, and FOOT. The latter is composed of the ankle and five complete digits. Between the digits an INTERDIGITAL WEB is developed. A more detailed discussion and description of the bones of the limbs and also of the general skeletal structure is left until later (p. 234).

The study of the external structure of the head reveals the presence of a very large mouth and a pair of eyes; the latter possess upper and lower eyelids, and normally protrude quite a distance above the dorsal surface. They can, however, be drawn back into cavities in the skull, and entirely covered over by the lower lids; the upper lids being immovable. A slight excrescence in the skin, just anterior to a line drawn between the two eyes, marks the BROW SPOT which at an early stage in development is connected with the brain. Still farther forward, near the anterior end of the head, is a pair of nostrils, the EXTERNAL NARES, which are the external openings of the olfactory organs. Posterior and somewhat lateral to the eyes, a pair of TYMPANIC MEMBRANES are to be found. These are circular, membranous, disc-like bodies embedded in the skin of the posterior head region. They cover over the internal portion of the ears, and also constitute a part of the auditory apparatus. (W. f. 83)

The outer covering of the Frog's body consists of a smooth, slimy skin which is heavily pigmented, particularly on the dorsal side of the animal. When preparations of the skin are studied under the microscope, it will be found to consist of

an outer protective portion, the EPIDERMIS, composed of several layers of epithelial cells. Both mucous and poison glands are formed in the epidermis. Lying below the epidermis is a second portion, the DERMIS, which is further divided into an outer layer, the STRATUM SPONGIOSUM lying next to the epidermis, and a thick, inner layer, the STRATUM COMPACTUM. The stratum spongiosum consists of a groundwork of connective tissue fibers in which are embedded numerous glands, nerves, blood vessels, lymph spaces, etc. The stratum compactum of the dermis consists of a thick layer of very heavy connective tissue fibers which, in general, run parallel to the surface of the skin. Vertical strands of connective tissue fibers are also present in this layer, which extend up through the stratum spongiosum to the epidermis. They aid in holding the various layers of the skin together. The human skin has somewhat the same structure (W. f. 76).

B. The Internal Structure of the Frog

The study of the internal structure of the Frog can best be started by cutting open the ventral body wall in a median line, running anteriorly to the girdle, or STERNUM, of the fore limbs, and posteriorly to the PELVIC GIRDLE of the hind limbs. After cutting through the loose outer layer of skin, the structure of which has been noted above, one comes into contact with the muscular body wall. Cutting through this layer opens up the body cavity, or COELOM, which consists in the Frog of a single large chamber, and thus exposes a number of the most important organs of the body, collectively spoken of as the VISCERA, which lie in it. Dorsal to the coelom lies the vertebral column, in a specialized portion of which is the central nervous system. This arrangement of the central nervous system, which is typical of the Vertebrates, is very different from that found in the higher Invertebrates in which the nerve cord lies directly in the coelom, close to the ventral body wall (W. fs. 75 A; 75 B).

Lying in the anterior end of the coelomic cavity, just below the sternum, is the HEART. It is enclosed in a delicate transparent sac, the PERICARDIUM (W. f. 83, *17–20*. In this figure the organs are viewed from the left side, instead of from the ventral surface). On either side of the heart, and extending posteriorly for a considerable distance, are the three brown-colored lobes of the LIVER. The liver is one of the most prominent organs in the abdominal cavity. The three lobes are connected by small tubes, known as the HEPATIC DUCTS, all of which open into a common GALL BLADDER. The latter can be noted as a small, green sac lying between and slightly dorsal to the lobes of the liver (W. f. 83, *13–14*). The pair of thin-walled LUNGS can be seen lying posterior to and on either side of the heart (W. f. 83, *25–26*).

Projecting posterior to the liver, the STOMACH can be seen. The anterior, or CARDIAC PORTION, merges without very great differentiation into the OESOPHAGUS which runs to the mouth (W. f. 83, *6*, *7*). The posterior, or PYLORIC, portion of the stomach is somewhat smaller than the cardiac portion. It ends at a definite constriction, the PYLORUS, at which point the coiled SMALL INTESTINE begins (W. f. 83, *8*). The first loop of the small intestine curves anteriorly and, together with the pyloric end of the stomach, forms a U-shaped structure between the two sides of which the important digestive gland, the PANCREAS, is situated. The latter is an elongated, yellowish body (W. f. 83, *15*). The BILE DUCT from the gall-bladder passes through the pancreas, from which it receives a branch, and then opens into the small intestine near the anterior end. The small intestine can be traced posteriorly, through a number of coils, to where it enlarges to form the LARGE INTESTINE, OR RECTUM, which merges into the CLOACA and continues to the exterior (W. f. 83, *9–11*). Near the anterior end of the rectum, attached by a mesentery to the wall of the intestine, a small red body of doubtful function, the SPLEEN, is to be seen (W. f. 83, *16*). The stomach and intestines are suspended in the coelom by specialized

sheets of connective tissue, known as MESENTERIES, which are attached to them, and which are also continuous with the layer of connective tissue, termed the PERITONEUM, which lines the coelom (W. f. 83, *12*; f. 75 B, *pr*, *pr'*).

The UROGENITAL SYSTEM, consisting of the KIDNEYS, BLADDER, GONADS, and associated DUCTS, lies near the dorsal wall of the coelom toward the posterior end. There is a pair of elongated, brownish-colored kidneys, one of which lies on either side of the coelom (W. f. 83, *29*). On the ventral surface of each kidney is a thin strip of orange-colored tissue, the ADRENAL BODY. The adrenals are one of the most important of the DUCTLESS GLANDS, or, as they are also called, ENDOCRINE ORGANS, and give off an essential secretion directly into the blood. A very fine duct, the URETER, passes posteriorly from the lateral edge of each kidney and opens into the cloaca (W. f. 83, *30*, *31*). The cloaca is a common chamber into which the intestinal, urinary, and genital ducts open. It is really the modified posterior portion of the rectum, and is present in all the Vertebrates, except in the higher Mammals. The urinary bladder also opens into the cloaca opposite to the ureters (W. f. 83, *10*, *11*, *32*, *33*).

The kidneys have the same structure in both sexes, but the gonads and ducts are somewhat different. In the male Frog, the TESTES are to be seen as a pair of small white bodies attached near the anterior end of each kidney (W. f. 83, *49*). Ducts from the testes lead directly through the kidneys and connect with the ureters. Thus in the male Frogs, the latter serve as a common duct for both the kidney secretions and the sperm, and are, therefore, designated as the UROGENITAL CANALS. A pair of yellowish, finger-like structures, known as the FAT BODIES, are to be seen which are also attached near the anterior end of each testis (W. f. 83, *34*).

In the female Frog, lying in the same region as the testes in the male, is a pair of lobulated OVARIES with the FAT BODIES attached to the anterior ends. A pair of comparatively large, white, convoluted OVIDUCTS are present, but are

not directly connected with the ovaries. Each enlarges posteriorly to form a uterus which opens into the cloaca. Anteriorly each oviduct ends in a funnel-shaped, ciliated opening situated near the anterior end of the coelom. In the breeding season the ovaries are very large and fill up a great portion of the body cavity.

The Coelom in the Higher Vertebrates

The general arrangement of the organs in the coelom is quite uniform throughout the Vertebrate series (W. fs. 75, 82–87), but in the Mammals including Man, the cavity of the coelom is completely divided by a sheet of muscular tissue, the DIAPHRAGM, into an anterior portion, or THORACIC CAVITY, which contains the heart and lungs; and a posterior portion, or ABDOMINAL CAVITY, which contains the remainder of the viscera (W. f. 86, *19;* f. 87, *13*).

C. THE ORGAN SYSTEMS

1. *Alimentary Canal*[1]

MORPHOLOGY. The plan of structure of the alimentary canal in the Frog, or in any other Vertebrate, is fundamentally the same as that which was noted for the first time in the study of the Earthworm, and then later in other of the higher Invertebrates. In all these forms, stated in the simplest terms, the alimentary canal consists essentially of a tube which begins with the mouth opening at the anterior end, runs through the body, and finally ends posteriorly at the anal opening. This tube may be straight as in the Earthworm, or greatly coiled as in the Clam and, in general, in the Vertebrate animals. (W. fs. 67, 74, 82–88.)

The mouth, or BUCCAL CAVITY, which is the specialized anterior end of the alimentary canal, is comparatively large in the Frog, and contains several kinds of structures (W. f. 83, *1*). The highly developed, muscular TONGUE lies in the

[1] Woodruff, pp. 154–60.

center of the lower jaw and extends from near the extreme anterior end to the posterior part of the mouth (W. f. 83, *3*). It is attached to the ventral wall of the mouth, at the anterior end only. As a result of this type of attachment, the free posterior end of the tongue can be extended quite a distance out of the mouth and thus made use of in the capture of insects or other small animal forms for food. The extension of the tongue is accomplished by rapidly filling a lymph space which lies beneath it. Posterior to the tongue, on the ventral wall of the mouth, is a raised, circular body, the GLOTTIS, which has a median, slit-like opening leading from the mouth into the trachea and then to the lungs (W. f. 83, *23*). Also, on either side near the posterior end of the tongue of the male Frog of some species there is a small opening through which air is taken into the vocal sacs. The latter are supposed to act as resonators and thus increase the volume of sound.

In the posterior part of the upper jaw on either side is the opening of a Eustachian tube which leads to the cavity of the middle ear (W. f. 83, *5*). Anterior to the openings of the Eustachian tubes are a pair of olfactory openings (INTERNAL NARES), and lying between are two groups of teeth, known as the VOMERINE teeth (W. f. 83, *4*). Numerous other very small teeth are borne around the margin of the upper jaw (W. f. 83, *2*). The teeth of the Frog are not used as masticating organs, but function solely for holding food which has been captured. The bony portion of the upper jaw is enclosed by a fleshy upper lip. The latter is lacking in the lower jaw, so that when the mouth is closed the lower jaw fits into a groove, the SULCUS MARGINALIS, inside the upper lip.

The buccal cavity ends posteriorly in the distensible, anterior end, or GULLET, of the oesophagus (W. f. 83, *6*). The latter continues as a small, undifferentiated tube through the anterior part of the coelom and then enlarges, as has been noted, to form the STOMACH which lies chiefly on the left

side of the animal's body. The stomach gradually decreases in size toward the posterior end and curves somewhat toward the right side of the body (W. f. 83, *7*).

A microscopical study of a prepared section through the wall of the stomach shows that it is comparatively thick and that it is composed of several layers of tissue as follows (W. f. 20)[1]: (1) The stomach is covered externally by a thin layer, the SEROSA, which is formed by the peritoneum of the coelom; (2) below the serosa is a heavy MUSCULAR LAYER composed of a thinner layer of longitudinal muscle fibers and a thicker layer of circular muscle fibers; (3) below the muscular layer is the SUBMUCOSA which consists of connective tissue and vascular elements; (4) finally, the stomach is lined by the essential endodermal MUCOSA. This layer consists, in general, of well-developed glands embedded in connective tissue elements. The glands secrete the enzymes, such as pepsin, and also other substances which are essential in digestion. The glands are larger in the cardiac portion of the stomach. (W. f. 20, *cg.*)

The SMALL INTESTINE consists of two portions; the anterior portion, known as the DUODENUM, which connects with the pyloric end of the stomach, and the posterior portion, known as the ILEUM. There is no particular structural differentiation to be noted between these two portions. The duodenum curves anteriorly and thus in the Frog forms with the stomach a U-shaped structure. The duodenum forms the left side of the U. The ileum begins at the upper left hand corner of the U and then curves abruptly posteriorly, forms a number of coils, and finally enlarges to form the LARGE INTESTINE, or RECTUM (W. f. 83, *8*, *9*).

The wall of the small intestine is somewhat thinner than the wall of the stomach, but has the same general arrangement of tissue layers (W. f. 20). The mucosa lining the intestine is composed not only of glandular cells for the

[1] Fig. 20 is a section through the small intestine, but it shows essentially the same structure.

secretion of certain materials, but also, and probably chiefly, of absorptive cells which are able to absorb the digested food materials (W. f. 20, *ep*, *cg*).

Physiology.[1] While the food of adult Frogs normally consists, for the most part, of small living animals, such as Insects or Worms, it is known that they will readily devour almost any kind of food which they can get in their mouths. They are cannibalistic and a large Bull Frog, for instance, will devour smaller individuals when the opportunity presents itself. The structure of the tongue, as previously noted, is of such a character that the posterior end of it can be very quickly thrust out from the mouth. The Frog is able to capture even a rapidly moving Insect with this specialized tongue. In such cases, after contact has been established, the Insect is held to the tongue by a sticky secretion and drawn back into the mouth.

The captured food is passed directly from the mouth, through the oesophagus, and into the stomach where, in the Frog, the first stage of digestion begins. The movement of the food throughout the length of the alimentary canal is brought about by peristalsis which consists essentially in a progressive wave of reduction in the diameter of the tube as a result of a contraction of the layer of circular muscle fibers in the walls. The peristaltic movement begins anteriorly and as it sweeps posteriorly forces the food-materials along with it.

The movements of the muscular walls of the stomach are of such a character as to thoroughly mix the food with the secreted enzyme, pepsin. This ferment, working in a slightly acid medium, due to the presence of a small amount of hydrochloric acid, is able to begin the process of digestion of the protein materials and to change them into peptones. Both the pepsin and the hydrochloric acid are secreted by the endodermal glands noted above.

When the proper condition of the food has been obtained,

[1] Woodruff, pp. 157–160.

the pyloric valve opens, and the partially digested food is passed through it and into the duodenum. Here it is acted upon by the digestive fluids secreted by the pancreas and carried to that region by the common bile duct. The pancreatic juice contains three principal digestive agents as follows: (1) TRYPSIN, which further acts on the peptones and completes their digestion; (2) AMYLOPSIN, which acts on the starches and changes them into sugar, and (3) LIPASE, which acts on the fats, splitting them into a fatty acid and glycerine. The digestive action of the pancreatic enzymes is dependent upon an alkaline condition of the food. Both the pancreatic juice and, particularly, the bile have an alkaline reaction and the food from the stomach with an acid reaction is mixed with these alkaline secretions before the final phases of digestion take place (W. f. 89). When digestion is completed, the liquid food is taken up, or absorbed, by the absorptive cells of the mucosa, lining the intestine and then turned into the circulatory system for transportation to all regions of the body.

THE FUNCTIONS OF THE LIVER. The liver, which is the largest gland in the body, has several functions particularly in connection with nutrition. In the first place, it secretes the alkaline bile which, as has been noted, aids in overcoming the acidity of the food from the stomach. It is believed that certain substances in the bile play additional rôles in converting starch into sugar, and also in emulsifying fats, so that they can be absorbed from the intestine without being chemically changed. Undoubtedly, bile also contains a certain amount of excretory materials. In the second place, the liver has the power of forming GLYCOGEN, or 'animal starch.' This carbohydrate is formed largely from sugar, but protein material can also be utilized. It will be noted below in the study of the vascular system that the liver receives the blood, containing absorbed food materials, directly from the digestive tract through the hepatic portal vein, and it is thus enabled to abstract the materials for the

formation of glycogen. In a well-fed animal, the liver contains considerable amounts of glycogen which can be returned to the blood stream as needed. Before being passed into the blood stream, the glycogen is changed into dextrose by the action of a specific enzyme in the liver. Finally, the liver aids in the process of excretion by changing the waste products in the blood into UREA; the latter is later taken from the blood by the kidneys. (W. pp. 167–168.)

2. *Vascular System* [1]

The vascular system of the Frog, just as previously noted in a number of Invertebrate animals, consists of a system of tubes and a circulating medium, the blood. Some of the tubes carry blood from the heart (ARTERIES) and others carry blood to the heart (VEINS). In the various tissues of the bodies, the arteries and veins are connected by a network of thin-walled vessels of microscopic size (CAPILLARIES). Spaces in the tissues (LYMPH SPACES) are of general occurrence throughout the body. The blood, which is propelled through the vessels by the well-developed heart, consists of the liquid PLASMA, together with an enormous number of atypical unicellular bodies, the CORPUSCLES, which float free in the plasma. The corpuscles are of two kinds: the RED CORPUSCLES which contain the red pigment, HAEMOGLOBIN, necessary in the process of respiration, and the amoeba-like WHITE CORPUSCLES, or LEUCOCYTES. (W. f. 7, H, I, J.)

HEART. This organ in the Frog is composed of three chambers, namely, a VENTRICLE and two AURICLES. Thus in its structure it may be said to occupy a middle position between the two-chambered fish-heart (W. f. 91; *au*, *v*), and the four-chambered heart of the highest Vertebrates (W. f. 92, *C*: *y*, *y'*, *z*, *z'*). There is a thick-walled, conical-shaped VENTRICLE which lies posterior. This is the main pumping part of the heart and, by its rhythmical contractions, drives

[1] Woodruff, pp. 161–174.

the blood through the arteries to all parts of the body (W. f. 92, *B*: *z*). Anterior to the ventricle there are two thinner walled cavities, the AURICLES, one to the right and one to the left (W. f. 92, *B*: *y*, *y'*). Opening into the right auricle, on the dorsal surface of the heart, is a large triangular sac, the SINUS VENOSUS (W. f. 92, *B*: *x*), which receives blood from all parts of the body through three veins; from the anterior regions through the right and left ANTERIOR VENAE CAVAE, and from the posterior regions through the POSTERIOR VENA CAVA (W. f. 92, *B*: *w*, *t*). Opening into the left auricle are the PULMONARY VEINS which bring blood to the heart from the lungs (W. f. 92, *B*: *e*). Leading from the ventricle is a vessel with heavy muscular walls, the CONUS ARTERIOSUS, which branches, soon after leaving the heart, to form three pairs of important arteries noted below. All the blood from the ventricle passes out through the conus arteriosus (W. f. 92, *B*: *ca*). The heart lies in a transparent sac, the PERICARDIUM, which is originally a part of the coelom, but in the adult condition becomes entirely shut off from the main body cavity.

VEINS. The three largest veins in the Frog are the right and left ANTERIOR VENAE CAVAE and the single POSTERIOR VENA CAVA, all of which open into the SINUS VENOSUS. Emptying into the anterior venae cavae are smaller veins which receive the blood from all the anterior parts of the body, except the lungs, as follows: Blood from the mouth region is collected by a pair of veins, the EXTERNAL JUGULARS; from the brain and other parts of the head region by a pair of INTERNAL JUGULARS; from the shoulders by a pair of SUBSCAPULARS; from the fore limbs by a pair of BRACHIALS, and from the side of the body and certain portions of the head by a pair of MUSCULO-CUTANEOUS veins. The blood from all of these veins finally empties into either the right or left anterior vena cava, from which it passes into the sinus venosus.

Posteriorly the blood is received into the posterior vena

cava from the liver through the HEPATIC VEINS, and from the kidneys and reproductive organs through the RENAL VEINS (W. f. 92, *B*: *s. q*). Emptying into these vessels are those which received blood from the body wall, hind limbs, etc., as follows: The liver receives venous blood from (*a*) the single, median ABDOMINAL VEIN (W. f. 92, *B*: *p*), which in turn arises from a pair of PELVIC VEINS, and from (*b*) the intestinal tract through the HEPATIC PORTAL VEIN (W. f. 92, *B*: *k*). The kidney receives venous blood from a pair of RENAL PORTAL VEINS which arise from the FEMORAL and SCIATIC VEINS of the hind limbs (W. f. 92, *B*: *n*).

ARTERIES. The CONUS ARTERIOSUS, which as previously noted leads from the ventricle, is the root of all the arteries in the body. It passes anteriorly from the ventricle, and, just beyond the anterior edge of the auricles, divides to form a right and left branch, from each of which arise three arteries, thus forming a total of six main arteries, or three pairs, from the heart. These are designated as a pair of COMMON CAROTIDS, a pair of PULMOCUTANEOUS, and a pair of SYSTEMIC ARCHES.

Each of the common carotid arteries divides into an EXTERNAL and an INTERNAL CAROTID, and these run anteriorly and supply the entire head region. They each give off a number of branches as they proceed (W. f. 92, *B*: *b*). The pulmocutaneous arteries carry blood to the respiratory organs. They divide into two main branches, one of which runs to the lungs (PULMONARY ARTERY) and the other (CUTANEOUS ARTERY) to the skin and body wall (W. f. 92, *B*: *d*, *f*). Each of the systemic arches curves dorsally and posteriorly. Posterior to the heart, and close to the dorsal body wall, the two arches unite to form a single large vessel, the DORSAL AORTA, from which branches arise that supply the important abdominal organs, the muscles of the abdominal body wall, and the hind legs (W. f. 92, *B*: *g*). Before uniting to form the dorsal aorta, the right and left systemic arches on each side gives off two branches: (1) the

OCCIPITO-VERTEBRAL, from which arises (*a*) the OCCIPITAL ARTERY supplying the jaws and nose and (*b*) the VERTEBRAL ARTERY which runs to the vertebral column, and (2) the BRACHIAL ARTERY which is distributed to the fore limb of that side and to the body wall nearby.

PORTAL SYSTEMS. Attention should be called to the RENAL PORTAL SYSTEM and the HEPATIC PORTAL SYSTEM. The renal portal system consists of a pair of veins which carry blood from the hind limbs to the kidneys. Into each of these renal portal veins three vessels empty, a FEMORAL and a SCIATIC VEIN from the hind leg, and a small DORSO-LUMBAR VEIN from the body wall. Thus, in the Frog the venous blood from the hind limbs and from a portion of the body wall, instead of emptying directly into the vena cava, passes by way of the renal portal vein into the kidneys. In Mammals the renal portal system is lacking (W. f. 92, B, C).

The hepatic portal system consists of a single large vessel, the HEPATIC PORTAL VEIN, which receives the venous blood, with absorbed food stuff, from the alimentary tract by means of the INTESTINAL, DUODENAL, and GASTRIC veins. This blood is then passed into the liver. After passing through the liver and being acted upon in various ways by the liver cells, this blood is collected into the posterior vena cava and taken to the heart (W. f. 93). In addition to the venous blood from the alimentary tract, the liver also receives a considerable supply of venous blood directly from the hind limbs through the abdominal vein.

COURSE OF THE CIRCULATION IN THE FROG. The general course of the circulation of blood in the Frog is as follows (W. f. 92, *B*): The venous blood from all parts of the body, except the lungs, is forced into the right auricle of the heart from the sinus venosus, by the contraction of the latter. When the right auricle contracts, this venous blood is forced into the right side of the common ventricle. The ventricle also receives, at the same time, by the contraction of the left auricle, the newly oxygenated blood which has been

received from the lungs by the pulmonary veins. This latter blood, in general, is received and remains in the left side of the ventricle, though there is more or less chance of mixing the venous and the oxygenated blood in the one-chambered ventricle of the Frog's heart.

The contraction of the ventricle now takes place, and, as a result, the venous blood from the right side is first forced out through the conus arteriosus. This latter vessel is so arranged that the venous blood is forced into the pulmocutaneous arteries which run to the lungs and the skin. The oxygenated blood from the left side of the ventricle is next forced out, and this blood passes from the conus arteriosus into either the carotid or systemic arteries which, as has been previously noted, supply almost all parts of the body.

Both the arteries and the veins break up in the tissues into a dense network of microscopic, connecting capillaries. The plasma of the blood and some of the white corpuscles are able to pass through the thin walls of the capillaries and thus come into direct contact with the tissues. The portion of the blood which leaves the closed vascular system through the walls of the capillaries is known as LYMPH, and it finally collects in the lymph spaces. The latter are comparatively large in the Frog. Contractile tissue is present in the walls of certain of the lymph spaces thus forming the LYMPH HEARTS. By means of these structures the lymph is pumped back into the vascular system. The greater portion of the blood, instead of passing through the walls of the capillaries, continues on through the capillaries and eventually into a vein leading back to the heart. (W. pp. 170–174.)

PHYSIOLOGY. During its circulation through the tissues of the body the blood gives off to the cells the oxygen, which was collected in the lungs, and the absorbed food materials received from the intestine. It also distributes certain materials from various glands of the body, such as sugar from the liver, which has been noted above, and various INTERNAL SECRETIONS, OR HORMONES. These are

considered in the following section. The blood picks up the waste products of the tissue cells and transports them to the excretory organs; the latter consisting of the lungs, skin, and kidneys. In a word, the blood carries on a general system of transportation as previously seen in other animals.

3. *Respiratory System*[1]

MORPHOLOGY. In the adult Frog the chief organs of respiration are the skin and the lungs. The skin is highly vascularized, and the blood is brought into close contact with the oxygen in the water or in the air. Each lung in the Frog consists of a thin-walled sac (W. f. 83, *26*). Leading anteriorly from each lung is a short tube, the TRACHEA (W. f. 83, *24*). The two tracheae, that is one from each lung, unite to form the LARYNGO-TRACHEAL CAVITY, lying just below the GLOTTIS (W. f. 83, *23*) in the mouth cavity, in the walls of which are the VOCAL CORDS. The latter are attached in such a way that the air in forcibly passing from the lungs sets them vibrating. The pitch of the sound produced can be altered by changing the tension of the cords.

In breathing, air is taken in through the openings of the external nares, and then passed into the mouth cavity through the internal nares (W. f. 83, *4*). When the mouth cavity contains sufficient air, the external openings are closed so that the air cannot escape through them. The muscles in the floor of the lower jaw next contract, and the air is thereby forced from the mouth cavity, through the glottis, and on into the lungs. Air is forced out of the lungs by a contraction of the body wall. The respiratory movement in the Frog is very different from that found in the higher Vertebrates, but the end result in either case is the same, namely, the forcing of the external air into the vascular lungs so that the respiratory exchange can take place.

PHYSIOLOGY. The essential phase of respiration, namely,

[1] Woodruff, pp. 168–170.

the gaseous interchange between cells of an organism and their environment, takes place in all the tissues of the body. However, in order for this interchange to take place in the higher animals, a respiratory mechanism, or system, such as has been noted above, must be present. In the adult Frog and in the higher Vertebrates, this system consists of the lungs and skin which serve as aërating agents, and the vascular system which supplies the means of transportation.

In the lungs, the blood gives off carbon dioxide and takes up oxygen. In the body tissues the blood gives off oxygen and takes up carbon dioxide. In both these phases of respiration, it is the red coloring matter, or HAEMOGLOBIN, present in the red corpuscles of the blood, which plays the leading rôle. This wonderful and complex chemical compound has the power of forming some kind of a loose combination with oxygen in the lungs, where the oxygen is abundant. In the body tissues, where carbon dioxide is abundant, it releases the oxygen and picks up the carbon dioxide which is carried to the lungs. It is generally believed that the plasma of the blood is also very important as a carbon dioxide carrier.

4. *Excretory System*[1]

Attention has already been given to the part played by the lungs and skin in the process of excretion. There now remains to consider the kidneys which in the Frog and other Vertebrates play the chief rôle in removing liquid nitrogenous wastes from the blood. This soluble nitrogenous waste compound, known as UREA, is a white crystalline substance, containing more than 46 per cent. of nitrogen, and has the chemical formula of $(NH_2)_2CO$. The actual synthesis of urea is accomplished primarily in the liver; its abstraction from the blood is accomplished by the kidneys. The kidneys also remove water and various inorganic salts. The com-

[1] Woodruff, pp. 175–180.

plete liquid waste excreted by the kidneys is known as URINE.

The pair of kidneys of the Frog, or MESONEPHROI as they are technically termed, lie, as has been noted (p. 189), in the coelom close to the dorsal body wall (W. f. 83, *29*). The microscopic study of these organs shows that they consist of an enormous number of tiny, coiled, tubular structures, known as the URINIFEROUS TUBULES, which are embedded in a mass of connective tissue. Each of these coiled tubes is, in a general way, comparable in its structure to a single nephridium of the Earthworm (W. f. 96). In fact, considered from an evolutionary standpoint, the Vertebrate kidney is generally believed to have arisen by a consolidation of the nephridia-like tubules to form the definite kidneys. (W. f. 98.)

Each uriniferous tubule has at one end a capsule-like structure, known as the MALPIGHIAN BODY. The latter is composed of an enlarged portion of the tubule (BOWMAN'S CAPSULE) which is lined with a peculiar type of cells and encloses a greatly coiled mass of capillaries. The latter constitute the GLOMERULUS. The wastes from the blood are given off in the glomeruli and also in certain other portions of the uriniferous tubules which are invested with a network of capillaries. The question as to the specific waste removed by these two portions of the uriniferous tubules is somewhat in doubt. (W. f. 98, C.)

The uriniferous tubules of each kidney open into a common collecting canal which, in turn, opens into the ureter (W. f. 83, *30*, *31*). In the Frog, there is no direct connection between the pair of ureters and the bladder; all of which open directly into the cloaca (W. f. 83, *10*). The arrangement in the cloaca is such that the urea from the ureters finds its way into the opening of the bladder (W. f. 83, *32*, *33*). It collects in that organ and is later expelled from the body through the cloaca. This condition in the Frog is different from that found in most of the Mammals. In the latter

the ureters open directly into the bladder. A tube from the bladder, known as the URETHRA, conveys the urea to the exterior through a special opening.

The blood is supplied to each kidney by the renal artery (W. f. 92, B, *l*), which is a branch of the dorsal aorta, and also by the renal portal vein (W. f. 92, B, *n*) which brings blood from the hind limbs. In the kidneys, the blood is passed through the Malpighian bodies and through the capillaries covering the tubules. During its passage through these structures, various inorganic salts in solution and other waste substances, which are present, are taken out of the blood, passed into and through the uriniferous tubules and, finally, into the cloaca and bladder by way of the ureters. Having been relieved of various waste materials, the blood is collected by the renal veins. The latter open into the inferior vena cava which connects with the sinus venosus of the heart (W. f. 92, B, *q*, *t*, *x*).

5. *Endocrine System*[1]

In the Frog and other Vertebrates, there are a number of very important glandular bodies, variously known as DUCTLESS GLANDS, ORGANS OF INTERNAL SECRETION, or the ENDOCRINE ORGANS. Structurally they are all characterized by the absence of ducts, so that the secretions which they manufacture, known as HORMONES, or INTERNAL SECRETIONS, are passed directly into the blood stream which carries them to all the tissues of the body. The cells of the various tissues pick out the specific hormone which is essential to their welfare. Remarkable results have been obtained within the last few years by the investigations upon the various endocrine organs, but even so our knowledge of them and of their physiological actions is limited. Some of the more important of the ductless glands may now be noted.

THYROID GLANDS. These consist, in the Frog, of a pair of tiny, spherical bodies of a yellowish color, situated one

[1] Woodruff, pp. 181–183.

on either side of the hyoid apparatus of the lower jaw and quite close to the laryngo-tracheal cavity. They are richly supplied with vascular tissue. Studied microscopically the thyroid tissue is found to consist of a connective tissue substratum in which are embedded numerous closed vesicular structures, termed FOLLICLES. The wall of the follicles is composed of a single layer of epithelial cells, cubical in shape, and enclosing a comparatively large central cavity. The latter contains a transparent material, known as the COLLOID SUBSTANCE, which is rich in iodin. It is apparently formed as a secretion of the epithelial cells which form the wall of the vesicle.

The blood, which passes through the thyroid glands, picks up a hormone which is essential to the life of the organism. It has been definitely shown in the Frog that this substance has a specific action upon the process of metamorphosis (Cf. p. 248). If there is a lack of it, metamorphosis will be inhibited. On the other hand, by supplying this hormone to young tadpoles, metamorphosis can be brought about at a very early stage. Its fundamental action in the tissues appears to result in an increase in the oxidative processes.

PITUITARY BODY. This endocrine gland is a composite structure found on the ventral surface of the mid-brain. It consists partly of nerve tissue, from the INFUNDIBULUM, and partly of an ectodermal ingrowth, the HYPOPHYSIS, from the dorsal wall of the anterior end of the alimentary canal (W. f. 134, *K*, *pty*; f. 104, C, *k*). Little is known as to the functions of the pituitary body, but it has been shown in Man that an enlargement of it is associated with an increase in the size of various tissues, particularly bone tissue of the limbs and face — a disease known as ACROMEGALY. In the Frog there is experimental evidence that the hormone of the pituitary body has a regulatory effect upon the thyroid gland.

ADRENAL BODIES. The pair of ADRENALS in the Frog has been previously noted (p. 189), one lying on the ventral surface of each of the kidneys. In the higher Vertebrates they

are small definite rounded bodies situated near the kidneys (W. f. 86, *16*). The hormone secreted by these glands is known as ADRENIN, and among other things it acts on certain nerve endings which, in turn, bring about a contraction of the muscles of the walls of the blood vessels, thus increasing the blood pressure.

COMBINATION GLANDS. It is worthy of note that a number of important glands with ducts also form hormones and other substances which are passed directly into the blood stream. The LIVER, for example, gives off bile which passes through the hepatic ducts into the intestine; but the liver also secretes urea and sugar directly into the blood stream. Again, the PANCREAS secretes through a duct certain important digestive enzymes into the small intestine, but the pancreas also secretes a hormone directly into the blood, which has a specific action on the kidney cells. Diabetes in Man is known to be due to a lack of this pancreatic hormone which is known as INSULIN. It has recently been isolated and is now being used in the treatment of diabetes. Finally, the sex gonads — both ovaries and testes — secrete certain hormones directly into the blood which have a very specific action on various structures of the body (W. p. 206).

6. *Nervous System* [1]

The nervous system of the Frog can be separated into the following components: (1) *Central Nervous System.* This consists of the BRAIN and SPINAL CORD. The latter lies dorsal to the alimentary tract, in a special cavity, the NEURAL CANAL, of the vertebral column. (2) *Peripheral Nervous System.* This consists of the paired CRANIAL and SPINAL NERVES which arise in the central nervous system, and run to all parts of the body. (3) *Autonomic, or Sympathetic, Nervous System.* This consists primarily of a pair of ganglionated cords lying close to the ventral body wall.

[1] Woodruff, pp. 183–202.

(4) *Sense Organs.* These may be regarded as specialized end organs of the peripheral nervous system, adapted for receiving various types of stimuli from the external environment. (W. f. 106.)

a. CENTRAL NERVOUS SYSTEM. The central nervous system arises, as will be noted later (p. 243), early in the development of the embryo by the definite infolding of a portion of the ectoderm of the dorsal body wall to form a hollow NEURAL TUBE which runs practically the entire length of the body. When first formed the neural tube shows very little differentiation, but in a short time the anterior end becomes enlarged and modified to form three divisions, known as the FORE-BRAIN, MID-BRAIN, and HIND-BRAIN. From these the entire brain of the adult Frog is formed. The remainder of the neural tube posterior to the brain retains throughout life a considerable degree of its early character and becomes the spinal cord of the adult. (W. f. 104.)

The Brain. Consideration may now be given to the external structure of the fully-developed Frog's brain as seen from the dorsal surface. The extreme anterior end consists of the fused OLFACTORY LOBES (W. f. 105, *B*, *a*). A pair of OLFACTORY NERVES, which innervate the olfactory sense organs, can be traced anteriorly from this region. Posteriorly, the olfactory lobes merge into a pair of elongated bodies, the CEREBRAL HEMISPHERES, which together constitute the CEREBRUM (W. f. 105, *B*, *b*). Posterior to the cerebrum is an unpaired structure, known as the DIENCEPHALON, which bears the PINEAL BODY (W. f. 105, *B*, *c*). The parts of the brain so far enumerated develop from the fore-brain. Just back of the diencephalon is a pair of egg-shaped OPTIC LOBES which constitute the mid-brain as seen from the dorsal surface (W. f. 105, *B*, *d*). Lying posterior and in close proximity to the optic lobes is a transverse ridge of tissue which constitutes the CEREBELLUM (W. f. 105, *B*, *e*). Just back of the cerebellum is the MEDULLA OBLONGATA (W. f. 105, *B*, *f*). This appears as a somewhat enlarged portion of the

anterior end of the SPINAL CORD. The latter continues posteriorly through the body without further marked differentiation (W. f. 105, *B*, *g*). The cerebellum and the medulla develop from the hind-brain.

The brain, as viewed from the ventral aspect, shows some additional structural features (W. f. 106). Beginning again at the anterior end, it will be noted that the fusion of the olfactory lobes is not so complete as on the dorsal side. The pair of olfactory nerves can be seen attached to the anterior end of the olfactory lobes (W. f. 106, *Ol*). The cerebral hemispheres are not so prominent on the ventral surface. Lying posterior to the cerebral hemispheres in the median line, is the heart-shaped INFUNDIBULUM, and just behind it is the HYPOPHYSIS. The latter is not composed of nerve tissue. The infundibulum and the hypophysis taken together constitute the PITUITARY BODY which as noted is one of the most important of the endocrine organs (p. 204). The portion of the ventral wall of the brain, which is ventral to the optic lobes and on which the infundibulum lies, is known as the CRURA CEREBRI. The pair of optic nerves, which innervate the retina of the eye, arise in the diencephalon and then run ventrally and cross in the OPTIC CHIASMA, just ventral to the infundibulum (W. f. 106, *Op*). The crossing of the optic nerves, so that the fibers from the right side supply the left eye and vice versa, is a noteworthy feature of the optic nerves in the Vertebrates.

One of the characteristic features of the Vertebrate central nervous system is the fact that it is hollow. The central cavity, when it is first formed, is quite large, but, in the adult condition, the walls of the central nervous system thicken and most of the original cavity is thus obliterated, leaving only a small CENTRAL CANAL which persists in the spinal cord throughout life. In the adult brain connecting with the anterior end of the central canal there is a series of cavities (VENTRICLES) connected by openings (FORAMINA). The ventricles in the brain are the remains of the original

cavity of this portion of the central nervous system (W. f. 104, *A*, *B*, *C*). The ventricles may be seen to good advantage in longitudinal sections through the brain in either a vertical (SAGITTAL) or a horizontal (FRONTAL) plane. If, for example, a frontal section through the brain is studied, the ventricles will be seen as paired structures. The first pair of ventricles (LATERAL VENTRICLES) form the cavities of the cerebral hemispheres and extend anteriorly to the olfactory lobes. The LATERAL VENTRICLES are connected posteriorly by a transverse opening (FORAMEN OF MONRO). The foramen of Monro communicates posteriorly with the single THIRD VENTRICLE which lies in the diencephalon. An OPTIC VENTRICLE is present in each of the optic lobes. These communicate with each other, also anteriorly with the third ventricle, and posteriorly with the single large FOURTH VENTRICLE which lies in the medulla. The fourth ventricle decreases in size posteriorly and merges into the central canal of the spinal cord.

The brain of the higher Vertebrates is characterized structurally by a great increase in the size of the cerebral hemispheres so that they overshadow the other parts. This increasing dominance of the cerebral hemispheres reaches its culmination in the Mammals, particularly in Man. The study of the brain of the Cat or of the Sheep gives a good idea of the structure of the Mammalian brain. (W. f. 105, *A–E*.)

The Spinal Cord. The study of a section of the spinal cord shows it to be roughly circular in outline, but with a considerable dorsoventral flattening (W. f. 107, *sp.c*). It is covered by two membranes: an outer, the DURA MATER, and an inner, the PIA MATER. The spinal cord proper consists of an outer portion, the WHITE MATTER, which is composed largely of medullated nerve fibers running in a direction parallel to the cord, and a central portion of GRAY MATTER (W. f. 107, *wm*, *gm*). In the layer of white matter, there are two clefts, one on the dorsal side of the cord (DORSAL

FISSURE), and one on the ventral side of the cord (VENTRAL FISSURE); the latter is the larger.

The gray matter, which is surrounded by the white matter, really forms the greater portion of the cord. It extends both dorsally and ventrally into the white matter in such a way that it forms a pair of DORSAL, and a pair of VENTRAL, HORNS. In the center of the gray matter and, therefore, in the center of the cord, is the CENTRAL CANAL, lined by epithelial cells (W. f. 107, *c.c.*). The gray matter contains great numbers of branched nerve cells intermingled with connective tissue elements. Some of the processes of these cells form the ventral roots of the spinal nerves, while others connect the various nervous elements of the cord (p. 211).

b. PERIPHERAL NERVOUS SYSTEM: I. CRANIAL NERVES. In the Frog, there are ten pairs of cranial nerves which arise from various regions of the brain as follows:

I. *Olfactory Nerves.* These are the first pair and arise, as previously noted, in the olfactory lobes. They pass anteriorly and somewhat laterally and innervate the olfactory sensory cells lining the nasal chambers (W. f. 106, *Ol*).

II. *Optic Nerves.* These arise in the diencephalon of the brain and, passing ventrally, cross in the mid-ventral line to form the OPTIC CHIASMA which has been noted above. From the chiasma, a pair of large optic nerves arise, and one runs to the retina of each eye and innervates the sensory cells there (W. f. 106, *Op, g*).

III. *Oculomotor Nerves.* These consist of a pair of small nerves which arise from the ventral wall of the mid-brain. They run, on each side, to the eye where, as the name indicates, they innervate certain eye muscles, as well as some other parts of the eye.

IV. *Trochlearis Nerves.* This pair of small nerves arises posterior to the optic lobes on the dorsal side of the brain and runs to the eyes where they innervate one of the eye muscles.

V. *Trigeminal Nerves.* This is a large and important pair of cranial nerves. Each trigeminal nerve arises by two roots from the side, and near the anterior end, of the medulla. The two roots unite to form the PROÖTIC ganglion from which arises the TRIGEMINAL NERVE proper. Each proötic ganglion marks the origin also of an AUTONOMIC, or SYMPATHETIC NERVE TRUNK. Each trigeminal nerve soon branches into two parts: (1) the OPHTHALMIC and (2) the MAXILLO-MANDIBULAR. The latter divides again into two branches: (1) the SUPERIOR MAXILLARIS and (2) the MANDIBULAR. The various branches of each of the trigeminal nerves innervate considerable portions of the facial region, more particularly around the mouth and tongue and the muscles of the lower jaw.

VI. *Abducens Nerves.* This pair of nerves arises from the ventral side of the medulla, close to, and on either side of, the mid-ventral line. Each nerve is distributed to certain muscles of the eye and also connects with a proötic ganglion.

VII. *Facial Nerves.* This pair of nerves arises from the medulla just posterior to the trigeminal nerves. Each facial nerve divides into two main branches: (1) the PALATINE and (2) the HYOMANDIBULAR. This nerve has a wide distribution in various parts of the face, nose, and throat.

VIII. *Auditory Nerves.* These arise from the medulla just back of the facial (VII) and run laterally on either side to the inner ear, which they innervate.

IX. *Glossopharyngeal Nerves.* These arise from the medulla posterior to the auditory (VIII) and together with the fibers of the VAGUS (X). They innervate certain muscles and lining membranes of the tongue and pharynx.

X. *Vagus Nerves.* These arise, as has been noted, in common with the glossopharyngeal. Each of the vagus nerves has two branches; the anterior one (RAMUS AURICULARIS) being much smaller. It runs forward and is distributed to the region of the tympanum of the ear. The

main branch of the vagus runs posteriorly and gives off a number of small branches which innervate the muscles of the shoulder. The remainder of the posterior main branch of this nerve is distributed to some of the important vital organs, such as the oesophagus, stomach, lungs, and heart (W. f. 106, *Xg*).

In the higher Vertebrates, two other pairs of cranial nerves are present: the SPINAL ACCESSORY (XI) and the HYPOGLOSSAL (XII), which are distributed to the muscles of the tongue, neck, and shoulder.

c. PERIPHERAL NERVOUS SYSTEM: II. SPINAL NERVES. There are ten pairs of spinal nerves in the Frog all of which arise in the spinal cord, and are distributed to various regions of the body. In the higher Vertebrates there is a considerable increase in the number of pairs of spinal nerves. Thus, in Man, there are 31 pairs. In all the Vertebrates, however, the structure of the spinal nerves is essentially the same. Each spinal nerve arises in the spinal cord by a DORSAL and a VENTRAL root. The two roots unite a short distance from the cord, to form a single nerve composed, therefore, of both dorsal and ventral elements (W. f. 107, *dr*, *vr*). On the dorsal root, just before the union with the ventral root, there is a swelling known as the DORSAL GANGLION (W. f. 107, *g*). The dorsal roots are known as the SENSORY, or AFFERENT, roots. As thus indicated the nerve fibers of which they are composed are connected to sensory nerve cells in the skin or other regions, which receive the stimuli (W. f. 107, *s*, *sf*). The stimuli thus received are conveyed to the spinal cord through the dorsal root. The ventral roots of the spinal nerves are known as the MOTOR, or EFFERENT, roots. They run from the spinal cord to the peripheral region where they connect with muscle tissue. The message, which has come through the sensory, afferent, dorsal root, is relayed by the spinal cord to the motor, efferent, ventral root, through which it reaches and stimulates the muscles necessary to bring about the appropriate response (W. f.

107, *m*, *mf*). The spinal nerves of the Frog are as follows:

I. The first pair of spinal nerves arises from the anterior end of the spinal cord posterior to the medulla. They emerge from between the first and second vertebrae. Each of these nerves usually gives off a small branch to the second spinal nerve and then continues, in a lateral direction, into the muscles of the body wall (W. f. 106, *Spn 1*).

II. This is a large pair of spinal nerves. Each one usually receives a branch from the first nerve and also a branch from the third. The branches from these three nerves form the BRACHIAL PLEXUS. The important nerves, which arise from this plexus, supply the muscles of the fore-limbs and shoulders (W. f. 106, *Br*).

III. The third pair of spinal nerves is small, and each, after giving off a branch to the brachial plexus as noted, can be traced laterally into the musculature of the body wall.

IV, V, and VI. These three pairs of small nerves, which arise from the spinal cord near the center of the abdomen, are distributed to the muscles of the body wall in the abdominal region (W. f. 106, *Sp 4*).

VII, VIII, and IX. These three pairs of large spinal nerves run posteriorly and laterally, and soon anastomose to form the large and important SCIATIC PLEXUS, from which arises the SCIATIC NERVE that innervates each hind leg. The seventh spinal nerve, anterior to the plexus, gives off a small nerve which is distributed to the abdominal muscles. The sciatic nerves can be traced into the legs. Numerous branches are given off which innervate the various leg muscles. (W. f. 106, *Js.*)

X. This pair arises near the posterior end of the spinal cord. The tenth nerve usually receives a small branch from the ninth, and together they form a small plexus which chiefly innervates parts of the urogenital system. An eleventh pair of spinal nerves is occasionally found which, when present, joins this plexus.

Histology of Nerve Tissue. The microscopic study of nerve tissue shows that it is composed of highly specialized nerve cells, or NEURONS. The neurons are structurally distinctive in that each possesses a relatively long process, termed the AXON, and one or more shorter irregular processes, termed the DENDRITES (W. f. 102; f. 7,G). The dendrites convey impulses to the cell, while the axon conveys impulses away from the cell. A nerve consists of a large number of axons bound together by connective tissue elements. Each of the axons in a nerve, if traced to its source, will be found to have its origin in a single neuron which may be located a very considerable distance from the peripheral end of the nerve. The neurons are not found indiscriminately scattered along the nerve fibers, but, in general, they are grouped in the central nervous system, and in ganglia such as those present on the dorsal roots of the spinal nerves.

The examination of a transverse section through a nerve shows that its method of construction may be compared in a general way to that found in a telephone cable. Covering the nerve is a connective tissue sheath, the PERINEURIUM, from which strands of connective tissue are given off. These strands divide the nerve into a number of compartments, the FUNICULI, each of which encloses several nerve fibers. Carrying the analysis further, each of the microscopic nerve fibers, or axons, is found to have a thin connective tissue sheath, the NEURILEMMA. The neurilemma encloses a comparatively heavy sheath of fatty tissue, the MEDULLARY SHEATH, which, in turn, surrounds the tiny, central axon. Each axon in this cable-like nerve is thus separated, or as we might say, insulated, from all the other nerve elements by the medullary sheath and neurilemma, and all the elements in a nerve are bound together by the connective tissue fibers which are continuous with the outer perineurium. A nerve fiber, such as just described, is known as the MEDULLATED type in distinction from the NON-MEDULLATED type, frequently found in the autonomic system, in which the medullary sheath is lacking.

d. AUTONOMIC, OR SYMPATHETIC, NERVOUS SYSTEM. There are two main nerve trunks in this division of the nervous system, which lie in the coelom, one on either side of the spinal column. Each trunk arises in the head region in the proötic ganglion which, it will be remembered, is formed by the trigeminal (V) cranial nerve. Each trunk can be regarded as a chain of ganglia. The ganglia receive one or more branches (RAMUS COMMUNICANS) from each of the spinal nerves near the origin of the latter from between the vertebrae (W. f. 106, *Sg*, *1*, *7*, *10*).

The branches of the sympathetic trunks innervate various important organs of the body. In the anterior part of the body these branches innervate the muscular walls of the subclavian and occipito-vertebral arteries, as well as the anterior ends of the oviducts. Farther posteriorly, the sympathetic trunks give off a number of branches which unite to form a very important nerve plexus, the SOLAR PLEXUS, from which sympathetic nerves are distributed to the important abdominal organs including the stomach, intestine, liver, pancreas, and parts of the urogenital organs. Still farther posteriorly, branches from the sympathetic trunks form the UROGENITAL PLEXUS which also innervates various of the urogenital organs. The sympathetic nervous system works independently. Hence the term AUTONOMIC NERVOUS SYSTEM is coming into general use. It is responsible for the involuntary control of many of the most important organs of the body.

e. SENSE ORGANS.[1] The sense organs are composed of ESSENTIAL and ACCESSORY parts. The essential parts of a sense organ consist of a specialized sensory tissue which is capable of receiving one or more types of stimuli from the external environment. In close connection with this essential sensory tissue, accessory structures are generally present in sense organs, which aid in various ways in bringing the stimulus to the nerve tissue.

[1] Woodruff, pp. 193–202.

I. *Contact Stimulus or Sense of Touch.* The sense of touch is located in the skin. Scattered through the skin there are specialized sensory end organs, known as TOUCH CORPUSCLES, which lie just under the epidermis. These touch corpuscles consist of a small group of flattened cells. Between these cells tiny nerve endings are found which are able to receive contact stimuli.

II. *The Chemical Sense.* The skin of the Frog, as a whole, is sensitive to chemical stimuli. If, for example, a drop of weak acid is placed on the skin of any region it will stimulate sensory cells there present, and the animal will endeavor to wipe off the acid. However, the chemical sense is best developed in the mouth and in the olfactory organs. The sense of taste is primarily a chemical one, and there are many groups of specialized sense cells scattered over the surface of the tongue and also, more or less generally, over the entire lining of the mouth. The taste organs consist of epithelial cells together with elongated sensory cells. Each of the latter is connected by fine processes with a nerve. The various chemical substances in the food stimulate, or excite, these sensory cells, and the stimuli thus received are passed to the central nervous system over the connecting nerve fibers.

The sense of smell, located in the nasal cavity, is also a chemical sense. The air, which is drawn into the nasal cavity through the external nares, passes by certain sensory cells which line this region. These cells are extremely sensitive to very minute quantities of chemical substances present in the air. A microscopic study of the tissue lining this cavity shows that this mucous membrane is made up of a basal connective tissue portion and, outside of this, a layer of OLFACTORY EPITHELIUM. The latter contains three types of cells, the OLFACTORY, BASAL, and INTERSTITIAL. The olfactory cells are the true sensory cells. They are greatly elongated, and at the outer free end of each, which forms a portion of the lining of the nasal cavity, there is a small

bunch of fine hair-like filaments, or cilia. These hairs, in some way, are influenced by the chemical substances present in the air, and the stimulus thus received is passed through the olfactory cells and finally reaches the nerve.

III. *The Sense of Hearing and of Position.*[1] The ear is a sense organ which is adapted for receiving two types of stimuli, those of sound and those of position, or equilibrium. In the higher Vertebrates, the ear consists of three parts: (1) the OUTER EAR, which is modified for collecting the sounds; (2) the MIDDLE EAR, which receives the sounds thus collected and conveys them to (3) the INNER EAR, which is the essential part, and contains the nerve tissue (W. f. 110). In the Frog, however, the outer ear is lacking, and the sound waves come first into contact with the tympanic membrane which is a portion of the middle ear.

Considering, first, the structure of the MIDDLE EAR, it is to be noted that it is an accessory structure by which the sounds are conveyed from the external environment to the inner, essential nervous tissue of the ear. The middle ear of the Frog, beginning at the outer surface of the body, consists of the tympanic membrane, as noted above (p. 186). The latter forms the closing membrane of a tube which constitutes the cavity of the middle ear, and which communicates with the mouth cavity by means of the EUSTACHIAN TUBE. The openings of the Eustachian tubes in the mouth have been previously noted. The tympanic membrane is of such a nature that the sound waves in the air cause it to vibrate, and these tympanic vibrations are then conveyed through the cavity of the middle ear and into the inner ear by a rod, the COLUMELLA, one end of which is attached to the tympanic membrane, and the other end to a portion of the inner ear. In the ears of the higher Vertebrates, there are three bones in the middle ear, known respectively as the MALLEUS, INCUS, and STAPES, or commonly, because of their shape, as the

[1] Woodruff, pp. 196–198.

hammer, anvil, and stirrup. Collectively they are known as the AUDITORY OSSICLES. (W. f. 110, *m, c, d, l, k.*)

The INNER EAR lies in a specialized bony cavity of the skull, known as the AUDITORY CAPSULE, and is surrounded by the liquid PERILYMPH which fills the auditory capsule. The inner ear consists of a very complicated structure, known as the MEMBRANOUS LABYRINTH, which contains the essential parts of the ear. The membranous labyrinth is composed of a large upper portion, the UTRICULUS, which is concerned with the sense of position, and a small portion lying below, the SACCULUS, which is concerned with the sense of hearing. The sacculus has an irregular, bag-like shape, is filled with a fluid known as the ENDOLYMPH, and contains the nerve endings. The vibrations of the columella cause vibrations in the endolymph and these, in some way, influence the nerve endings. The stimuli thus received are conveyed to the brain by the auditory nerves (eighth cranial) and thereby give rise to the sense of hearing. (W. f. 109, *u, s.*)

In the higher Vertebrates, including Man, a greatly coiled structure, known as the COCHLEA, develops from the sacculus (W. f. 110, *i*). It is regarded as a derivative of the sacculus of the ear in the lower Vertebrates (W. f. 109, *l*). The cochlea becomes the essential part of the ear for the function of hearing. It contains an extremely complex structure, known as the ORGAN OF CORTI, in which the nerve endings are located. The vibrations of the auditory ossicles are communicated to the endolymph present in the cochlea, as well as in the rest of the membranous labyrinth, at a certain region of the vestibule (W. f. 110, *l, g*).

The utriculus, in which the sense of position is located, consists of a basal part attached to the sacculus, and bearing three semicircular canals which lie primarily at right angles to each other. The utriculus also contains endolymph surrounding the sensory nerve cells. Movements in the endolymph stimulate the sensory cells, and thus bring about a sense of position. Experimental work has shown clearly that

when the labyrinth with the semicircular canals is removed from both sides of the head, the Frog is not able to regulate its position at all. If the labyrinth is destroyed on only one side an asymmetrical attitude of the Frog results; the head being tipped one way or the other depending upon which side is operated on (W. f. 109, *u*, *ca*, *ce*, *cp*; f. 110, *g*, *e*).

IV. *The Sense of Sight.*[1] The eyes, which have as their specific function the reception of light, or PHOTIC, stimuli, lie in special cavities, or ORBITS, on the dorsal and lateral wall of the head (p. 186). The eye is spherical in shape, and is composed of several layers of tissue. It is covered on the outside by a strong, connective tissue sheath, known as the SCLEROTIC COAT, which forms a continuous covering of the eye except for one small area in the posterior region where it is pierced by the optic nerve, running from the eye to the brain. (W. f. 112 A, *q*.) Posteriorly, the sclerotic coat of the eye is opaque, but in the front of the eye there is a transparent region, known as the CORNEA, through which the light rays can pass into the interior of the eye (W. f. 112 A, *k*).

Attached to the sclerotic coat are several eye muscles which move the eye in various directions. In the first place, there is a large RETRACTOR BULBI muscle, attached to the posterior portion of the eyeball. When this muscle contracts the eye is drawn back into the orbit. The eye is protruded from the orbit by the contraction of the LEVATOR BULBI muscle, which lies obliquely along the ventral part of the orbit.[2] The other muscles are (1) a pair, the SUPERIOR and INFERIOR RECTI, which roll the eye up or down; (2) a pair, the ANTERIOR and POSTERIOR RECTI, which roll the eye to the right or left, and (3) a pair, the SUPERIOR and INFERIOR OBLIQUE muscles, which give the eye oblique movements. (W. f. 112 A, *d*, *g*.)

Lying within the sclerotic layer is the thin CHOROID LAYER (W. f. 112 A, *p*). It contains many blood vessels, is deeply pigmented, and, anteriorly, it forms the colored portion of

[1] Woodruff, pp. 198–202.

[2] The two muscles just described are not present in the human eye.

the eye, or IRIS, in the center of which is a circular opening, the PUPIL (W. f. 112 A, *i*, *l*). The iris also contains muscular elements, and, in its functioning, may be compared to the iris diaphragm in a camera. When there is not much light the *radiating* muscles in the iris contract thus enlarging the pupillary opening, through which light is admitted to the interior of the eye. In bright light, the *circular* muscles of the iris contract and this results in a constriction of the pupillary opening so that only a small amount of light is admitted to the deeper-lying, sensitive portions of the eye.

The innermost layer of the eye is the RETINA (W. f. 112 A, *o*). This, it should be noted, is the essential part of the eye and contains the specialized sense cells which are adapted for receiving the photic stimuli and passing them on to the optic nerve. The retina lines the greater part of the eyeball, but does not extend to the anterior surface as do the other two layers. It consists of (1) a thin outer layer containing pigmented cells, which lies next to the choroid coat of the eye and (2) a thicker sensitive layer containing the nerve tissue, which forms the inner lining of most of the eye cavity. The sensitive layer of the retina is an extremely complex structure, and a microscopic study of properly prepared material shows that it is composed of no less than nine layers of tissue, the most external of which is the light-receiving tissue, known as the layer of RODS and CONES. This layer consists of very highly specialized cells which show two structural types, the rods and the cones. The former are more numerous and appear as narrow, elongated bodies with distinct striations. The rods show a differentiation into a larger and a smaller type. The cones are considerably larger and not so elongated as the rods. (W. f. 112 B, *r*.)

The optic nerve enters the retina posteriorly. It passes through the retinal layers giving off fine branches which run to all portions of the retina and, finally, innervate the essential rod and cone cells. The part of the retina, where the optic nerve enters, lacks these light-receiving elements,

and is designated as the BLIND SPOT (W. f. 112 A, *t*). Just to one side of the blind spot is the region of the retina (*fovea centralis*) where the vision is most acute (W. f. 112 A, B, *x*).

Having now considered the three separate layers, which form the wall of the eyeball, mention should next be made of an important accessory structure, the CRYSTALLINE LENS, which lies anteriorly (W. f. 112 A, *m*). The lens serves to focus the light rays on the retina, and it is capable of being adjusted for either near or far objects. It is enclosed in a membrane to which the CILIARY MUSCLES, located near the base of the iris, are attached. These muscles act in such a way as to alter the shape of the lens so that either near or far objects may be brought to a focus (W. f. 112 A, *r*). The small cavity of the eyeball lying between the iris and the lens is known as the POSTERIOR, OT INNER, CHAMBER and the larger cavity lying between the iris and the cornea is known as the ANTERIOR, OT OUTER, CHAMBER. Both are filled with a watery, transparent fluid, known as the AQUEOUS HUMOR (W. f. 112 A, *h*, *i*). Back of the lens and surrounding it is the VITREOUS CHAMBER, which is the largest chamber of the eye, and contains a heavy transparent fluid, the VITREOUS HUMOR (W. f. 112 A, *s*).

Functions of the Nervous System

The nervous system of an animal is responsible for the coördination of the various parts of the body in response to stimuli received either from the external environment or from the internal organs.

In considering the functions of the various parts of the nervous system it is to be noted that the brain is regarded as the main directing center of the body. In it the endless coördinations are brought about which are necessary in receiving all types of stimuli and translating them into action. In a general way, it can be stated that the spinal cord is dominant to the peripheral regions of the nervous system; that the brain is dominant to the spinal cord, and that the

cerebral hemispheres at the anterior end of the brain are the chief dominating and directing agencies of the nervous system as a whole, and, therefore, of the entire body. Furthermore, if the Frog can be said to possess the power of purposive thinking, or intelligence, it is located in the cerebral hemispheres.

However, experimental work involving the complete removal of the cerebral hemispheres of the Frog has shown that such an animal can still live and carry on most of the functions in a normal manner except that a certain amount of spontaneity is lacking. Although it has been claimed that the chief coördinating centers of the Frog's brain lie in the optic lobes, it can be shown experimentally that the brain of the Frog as far back as the medulla may be completely extirpated, and the animal will still live and be able to carry on a number of regular coördinated movements. It is clear, therefore, that such actions do not necessarily involve the anterior parts of the brain. Actions of this type which do not involve the higher parts of the brain are known as REFLEX ACTIONS. The hind-brain and the anterior end of the spinal cord are particularly adapted for the higher types of reflex action. There are many reflex actions of a lower grade, which are apparently located even farther posteriorly in the spinal cord.

A good example of reflex action may be seen in certain of our own reactions. If, for example, a finger touches a hot surface it is immediately jerked away. This is a reflex action and as such does not involve definite thought on our part. In such an action the impulse from the sensory cells in the skin goes into the central nervous system through the dorsal root of a spinal nerve. In the spinal cord, the impulse is relayed to the appropriate motor cells, and, leaving the spinal cord through a ventral root, reaches the appropriate muscles (W. f. 107). In learning to walk, each step involves thought, but after a time the actions involved become largely reflex, and the higher brain centers are thereby freed for

other more important functions. Thus it is with many other similar actions.

7. *Muscular System* [1]

Following the study of the nervous system, it is in order to consider the specialized contractile MUSCLE TISSUE, which, working under the control of the nervous system, causes, by its contraction, the various and almost continual movements that occur in the higher animals. Muscular tissue is one of the most highly specialized tissues of the animal body. It may be classified as (1) the STRIATED, or VOLUNTARY, muscle tissue, the movements of which are under voluntary control, and (2) the NONSTRIATED, or INVOLUNTARY, muscle tissue which is not under direct control of the will. This latter type of muscle tissue, examples of which may be found in the various vital organs, is under the general control of the autonomic nervous system. CARDIAC muscle tissue in the heart is sometimes regarded as a separate type of muscle tissue.

The *nonstriated* muscle tissue which, as has been noted, forms the muscular layers in the walls of a number of the important organs, such as those of the alimentary canal (W. f. 20), blood vessels, and urinary bladder, is regarded as a simpler type than the striated. A microscopic examination shows that it consists of elongated, spindle-shaped cells, each with a nucleus which is also elongated in the same direction as the cell (W. f. 7, *F*). The muscle cells are frequently branched at the ends. Also there is a considerable variation in their length. For example, in the walls of the blood-vessels the cells are short and correspondingly thick, whereas in the walls of the bladder they are long and thin. The cytoplasm shows a fine longitudinal striation, which is very different from the heavy, transverse striations of the voluntary type of muscle tissue. The spindle-shaped cells lie close together with a certain amount of cement

[1] Woodruff, pp. 138–139.

substance and connective tissue elements intermingled. Thus they are closely held together and work as a unit. The rate of contraction in unstriated muscle tissue is much slower than that of striated muscle tissue.

The *striated* muscle tissue of the body is largely centered in the muscles of the body wall and of the appendages. It is separated into definite units, the muscles proper. For example, in the hind limb of the Frog there are some eighteen separate and distinct muscles which bring about the various movements of the leg. All these muscles are attached to the bones by means of specialized connective tissue elements, known as TENDONS. In general, one end of a muscle, known as the ORIGIN, is attached to an immovable bony structure, while the opposite end, known as the INSERTION, is attached to a movable bony structure. The GASTROCNEMIUS MUSCLE, which is a large muscle in the calf of the leg, may be taken as an illustration of the origin and insertion of a muscle. It has a double origin in (1) the distal end of the large thigh bone, or FEMUR, just above the knee joint, and (2) in a tendon which is attached to a tendon from the triceps muscles higher up the leg. These points of origin are relatively immovable. The insertion of this muscle is in various foot bones. When it contracts it causes an extension of the foot, and also a movement of the leg at the knee joint.

A muscle that produces an extension, such as just noted in the foot, is known as an EXTENSOR; one that causes a flexion of the joint is known as a FLEXOR. The gastrocnemius muscle produces both these movements. There are a number of other types of muscles classified according to the movement which they produce. Among these are the ADDUCTOR muscles which draw the limb in a posterior direction toward the long axis of the body; the ABDUCTOR muscles which draw the limb in an anterior direction toward the long axis of the body; the LEVATOR muscles which raise some part of the body, such as the lower jaw, and the DEPRESSOR muscles which work in an opposite direction.

A microscopic examination of *striated* muscle tissue shows that it is always enclosed in a connective tissue sheath, known as the PERIMYSIUM, or FASCIA, which contains blood vessels and nerves. The fascia continues beyond the end of the muscles as a tendon which is attached to the bone tissue. Strands from the perimysium radiate throughout the body of each musclė and separate it into a number of muscle bundles, termed FASCICULI. Each fasciculus contains a great many individual muscle fibers which are separated from each other, in turn, by a further continuation of the perimysium, known as the SARCOLEMMA. The individual muscle fibers, each surrounded by the sarcolemma, are the ultimate units of muscular structure, and any muscle contains an enormous number of such units (W. f. 7, *E*). Distributed through each fiber are several elongated nuclei. It is believed that each fiber represents a greatly modified, single cell in which the original nucleus has divided many times without a division of the cell body. The cytoplasm, or SARCOPLASM, of the striated fibers exhibits both a transverse and a longitudinal striation, the former being much the more prominent. The longitudinal striations are due to the presence of tiny, filamentous strands, the SARCOSTYLES, which extend longitudinally through each cell. These are supposed to be the contractile elements in the fiber. With a sufficiently high magnification, it is apparent that the transverse striation is due to the presence of alternate light and dark bands which run across the muscle. The muscle fibers are thus divided into segments, or SARCOMERES, which constitute the dark areas, and these are separated by light bands. When a muscle is contracted, the bands are more closely approximated than when the muscle is relaxed.

The *cardiac* type of muscle tissue, which forms the walls of the heart, apparently represents a type of muscle tissue which is between the non-striated and the striated. The cardiac tissue cells, while retaining their identity as in the non-striated tissue, are attached to each other by strands of cyto-

plasm. They have, however, definite transverse striation, and in that regard resemble the striated muscle tissue.

Contraction of Muscle Tissue. The question as to what causes muscle tissue to contract, when the proper stimulus is received from the nervous system, is one which is still unsolved although many theories have been proposed. In considering this problem, it is interesting to know that muscle tissue can contract when removed from the body of an animal. Contractility, therefore, is not dependent upon any connection with the body. As an example of this, the study of a 'muscle-nerve preparation' is of value. Such a preparation is made by removing a muscle from an anesthetized animal, say the large gastrocnemius muscle from the hind leg of a Frog. The dissection should be done in such a way as to leave the sciatic nerve, which innervates this muscle, attached to the leg. The dissected muscle, with the attached nerve, can be kept wet with a normal salt solution. The use of such a solution prevents the tissues from drying, and when so treated they can be kept alive for the experimental work for some time. The muscle can now be attached to an immovable body at one end, which represents the origin, and to a movable body at the other end, which represents the insertion. The nerve may now be stimulated in various ways, such as by contact, electrical current, or chemical solutions. When the nerve is stimulated at the end away from the muscle a nerve impulse passes through it and into the muscle in apparently the same way as if it were normally situated in the body, and received a stimulus from the spinal cord. The result is also the same, and the muscle immediately contracts, thereby causing a movement at its insertion.

The above experiment demonstrates that living muscle tissue will contract outside the body, and also that the nerve can be artificially stimulated to bring about the muscular contraction. The question as to what actually takes place under such circumstances in both the muscle and nerve tissue is,

for the most part, unknown although it has been the subject of a great deal of experimental work.

8. *Connective and Supporting Tissues*[1]

The connective tissues of the body include a variety of different types, all having as their chief functions the support and protection of the various organs. They are divided into two types, the EXOSKELETAL and the ENDOSKELETAL.

The EXOSKELETAL structures are external, and they develop from both inner and outer layers of the skin. In some Vertebrate animals, as for example, the Turtle, the exoskeleton forms a protective covering over practically the entire body. In other groups of Vertebrates, the exoskeletal structures, while not forming a covering over the entire body, are present in the form of nails, hair, feathers, etc. In the Frog, all such exoskeletal structures are lacking.

The ENDOSKELETAL structures are internal and include a number of types of connective tissue proper and also bone which is to be regarded as the highest development of the endoskeleton. In general, all of the connective tissues contain a relatively large amount of ground substance, or MATRIX, which is intercellular in position, that is to say, this material lies outside the cell walls, between the cells. In some of the connective tissues the ground substance constitutes the larger part of the tissue. It develops very early in the Frog embryo as a homogeneous substance which later becomes modified in various ways to form the main body of the different types of connective and bone tissue. For example, it may remain largely unchanged, as in some of the lower types of connective tissue; it may become a dense fibrillar material, as in a tendon; or it may become largely infiltrated with certain inorganic salts, chiefly calcium carbonate, and form the basis of the hard bone tissue.

WHITE FIBROUS TISSUE. There are several different

[1] Woodruff, pp. 140–142.

kinds of connective tissues proper. One type, which has a very wide distribution, is known as the WHITE FIBROUS TISSUE. This may be obtained from almost any region of the body; for example, under the skin, or surrounding the muscles and nerves, or forming the supporting framework in various organs or, as TENDONS, attaching the muscles to the bones. When examined microscopically, the white fibrous tissue will be found to consist of a considerable proportion of ground substance in which are embedded bundles of white fibers having a characteristic wavy appearance. The ground substance also contains a number of elastic fibers, mentioned below. Scattered among the fibers and embedded in the ground substance are numerous connective tissue cells, known as FIBROBLASTS. These are elongated, spindle-shaped cells which have a tendency to stretch out along the fibers.

ELASTIC TISSUE. Another type of connective tissue, which is found to some extent intermingled with the white fibrous type, is known as ELASTIC TISSUE, and it consists of heavier, straight fibers which frequently branch. The elastic fibers are found in abundance in the walls of the blood vessels, and they also form certain ligaments. The construction of elastic tissue is such that a considerable degree of elasticity is present. Thus when tension is applied it will stretch and then return to a normal condition after the tension is released. This condition is very different from that present in the tendons of the body, which consist almost entirely of white fibers. A tendon lacks elasticity and will break under tension rather than stretch. Generally the white fibers and the elastic tissue are found to be more or less intermingled in the various connective tissues. For example, the LIGAMENTS contain a great deal of the elastic tissue and very few of the white fibers, while the reverse is true of the tendons.

FATTY, OR ADIPOSE, TISSUE. This type of tissue is found more or less scattered throughout the body, and is generally regarded as a type of connective tissue in which the cells

have become somewhat enlarged and atypical in shape as a result of fat storage.

CARTILAGE is a highly developed type of connective tissue, which is particularly abundant in the embryo. Most of the bones in the body are first formed as cartilage, and then this is later changed into true bone. Some of the cartilaginous material, however, remains unchanged throughout life. Cartilage is marked by the presence of an exceptionally large amount of transparent, intercellular ground substance which possesses great strength (W. f. 7, *D*). The cartilage cells are embedded in this matrix in numerous cavities, known as LACUNAE. The latter may contain one, two, or even more, cells. There are various kinds of cartilage, depending upon the character of the ground substance. HYALINE CARTILAGE has a homogeneous matrix, but, in the mixed and fibrous types of cartilage, this ground substance is fibrillated due to the presence of either white or elastic fibers, or both. Hyaline cartilage is the more common type, and it is found in the joints, in the sternum, and in a number of other places in the body.

BONE. The greater portion of the bone tissue of the body, as has been noted, is first formed as a cartilage. Such bones are, therefore, known as CARTILAGE BONES in distinction to a less frequent type, known as MEMBRANE BONES, in which the cartilage stage is lacking, and the bone tissue develops by an ossification of certain membranes. The general structure of mature bone shows a resemblance to cartilage in that the bone cells, or OSTEOBLASTS, are embedded in cavities in the matrix in somewhat the same way as in cartilage. The microscopic structure of bone can be seen to good advantage in a properly prepared transverse section through one of the leg bones, for example, the femur. Such a section shows that the bone is not solid all the way through, but consists of an outer cylinder of bone tissue enclosing an internal cavity which runs the length of the bone. In life, the cavity is filled with a soft, highly vascularized tissue, the BONE MARROW.

The bone tissue is covered on the outside by a connective tissue sheath, the PERIOSTEUM, and is "arranged in concentric layers, or LAMELLAE, which contain numerous lacunae in which lie the BONE CELLS. From the lacunae fine, branching tubes, or CANALICULI, containing processes from the bone cells, are given off which extend in all directions and anastomose with the canaliculi of neighboring spaces." (Holmes.) Next to the periosteum, the osteoblasts continue to add new bone during development so that the bone increases in diameter by the addition of outside layers. The bone tissue may also increase to a certain extent by the addition of bony tissue in the marrow cavity.

9. *Skeleton*[1]

The skeleton of a Vertebrate animal may be divided into the AXIAL SKELETON consisting of the skull and vertebral column, and the APPENDICULAR SKELETON consisting of the limbs and the limb girdles.

a. AXIAL SKELETON : I. THE SKULL. The skull consists of two portions: the CRANIUM, which is the brain case, and the FACIAL portion. (W. f. 81 A.) Making up the skull is a considerable number of bones and of permanently cartilaginous elements. The cranium in the Frog is small, narrow, and elongated in the direction of the long axis of the body. It encloses and protects the brain, together with the auditory and olfactory sense organs. At the posterior end of the cranium there is a large opening, the FORAMEN MAGNUM, through which the spinal cord leaves the cranium and passes into the vertebral column. Surrounding the foramen magnum are the EXOCCIPITAL bones, each of which bears a rounded prominence, or OCCIPITAL CONDYLE, which articulates with the first vertebra and thus forms the connection between the skull and the vertebral column (W. f. 81 A, *ex. oc*). Just anterior and lateral to each exoccipital bone, is a PROÖTIC bone (W. f. 81 A, *pr. ot*). Lying in the anterior

[1] Woodruff, pp. 142–147.

portion of the cranium and also forming the posterior wall of the nasal cavity is an unpaired bone, known as the SPHENETHMOID (W. f. 81 A, *sp. eth*). These five bones, that is, a pair of occipitals, a pair of proötics, and the unpaired sphenethmoid constitute the cartilaginous bones of the Frog's cranium.

There are also a number of membrane bones which form the dorsal covering of the cranium. There is a pair of long, narrow bones, the FRONTO-PARIETALS, which result from a fusion of two pairs of bones, as found in the higher Vertebrates, namely the frontals and parietals. The fronto-parietal bones connect posteriorly with the proötics and the exoccipitals, anteriorly with the sphenethmoid, and form the main portion of the dorsal wall of the cranium (W. f. 81 A, *fr. pa*). A pair of small irregular bones, the NASALS, form the dorsal wall of the olfactory capsules. On the ventral surface of the olfactory capsules is a pair of small bones, the VOMERS (W. f. 81 A, *vo*), which bear the vomerine teeth. The ventral wall of the cranium is chiefly formed from a large, unpaired, T-shaped bone, the PARASPHENOID, the long stem of which extends anteriorly, and the transverse portion posteriorly and laterally, running under each of the auditory capsules.

The facial portion of the skull consists of the upper and the lower jaws and the hyoid cartilage which, with its bony processes, forms a plate-like structure in the ventral wall of the mouth cavity where it supports the tongue. The hyoid in the Frog is not so complete as in the Fishes where it forms the elaborate gill-bearing, or visceral, skeleton (W. f. 81 A, *ac. hy*, *b. hy*).

The bones of the *upper jaw* are immovably fastened to the cranium. They consist of a pair of PREMAXILLARY bones which form the extreme anterior portion of the upper jaw, a pair of MAXILLAE which are posterior to the premaxillaries and form the sides of the upper jaw, and a pair of QUADRATOJUGALS which form the posterior portion of the upper jaw. (W. f. 81 A, *pmx*, *mx*, *qu. ju.*)

Each side of the *lower jaw* has as its basis a cartilaginous rod, known as MECKEL'S CARTILAGE. Anteriorly each rod is largely covered by a DENTARY bone, and posteriorly by an ANGULO-SPLENIAL bone. The jaws are attached to the cranium by a rather complicated suspensory apparatus consisting of three bones on each side, namely the SQUAMOSAL, PTERYGOID, and PALATINE (W. f. 81 A, *sq*).

The MAMMALIAN SKULL is considerably modified from that just noted in the Frog (W. f. 81 B, *1–9*, *36–39*). In the first place the increase in the size of the brain has brought about an increase in size of the cranium as compared with the facial region. This condition is seen in the most marked degree in the skull of Man (W. *f.* 87, *1; f.* 186; note the relative size of the cranium in Man and Gorilla). There is also a great tendency toward a complete fusion of certain bones so that the adult skull comprises a smaller number of separate bones than that of the embryo. Thus in early adult life, there are 22 separate bones in the human skull. This number is considerably less than it is in earlier years, and it is even more reduced in old age.

Teeth. The teeth of all Vertebrates are regarded as homologous structures which, in their evolutionary history, have developed from the placoid scales of certain Fishes. They are composed of a thin, outer covering of ENAMEL which forms from the epithelium lining the mouth, and DENTINE which develops from the underlying mesodermal tissue. The latter constitutes the bulk of a tooth. Teeth in the various Vertebrate groups are subject to very great variation in number, shape, and function. In certain of the higher Vertebrates, including Man, the teeth are placed in deep pits, or ALVEOLI, in the jawbones. The portion of the tooth within an alveolus is known as the ROOT, while the exposed enamel-covered portion is known as the CROWN. We recognize four types of teeth in the higher forms, which, beginning anteriorly, are known as the INCISORS, CANINES, PREMOLARS, and MOLARS (W. f. 81 B, *40–43*).

In Man and most of the Mammals, two sets of teeth are formed. The first set in Man, the MILK TEETH, are replaced in the early years of childhood by the permanent teeth which develop in the jaws back of the first set. The number of milk teeth varies somewhat, with a normal of 20, while in the permanent set there are 32 teeth, divided so that each half of each jaw contains 2 incisors, 1 canine, 2 premolars, and 3 molars. In order to state concisely the number of teeth in an animal a DENTAL FORMULA is made use of in which the letters *i*, *c*, *p*, and *m* indicate the kinds of teeth, and the numbers in *half* of the upper and lower jaw are shown by figures above and below a line. Thus the dental formula of Man is indicated as $i\,\frac{2}{2}$, $c\,\frac{1}{1}$, $p\,\frac{2}{2}$, $m\,\frac{3}{3} = 32$.

b. AXIAL SKELETON: II. VERTEBRAL COLUMN. The vertebral column of the Frog is very short (W. f. 81 A, *v. 1*, *v. 9*). It consists of nine typical vertebrae, together with a narrow, rod-like, unsegmented, posterior extension, known as the UROSTYLE (W. f. 81 A, *ust*). Each vertebra consists of a solid oval portion, the CENTRUM, a portion of which occupies the original position of the notochord, ventral to the spinal cord (W. f. 79, *c*). Dorsally and laterally on each centrum a bony structure, known as the NEURAL ARCH, is developed around the spinal cord (W. f. 79, *ped*). The space between the neural arch and the centrum in each vertebra constitutes the NEURAL CANAL in which the spinal cord lies (W. f. 79, *vf*; f. 87, *27*). Each neural arch has a dorsal projection, the NEURAL SPINE (W. f. 79, *ns*; f. 81 B, *12*; f. 87, *29*), and, except in the first vertebra, a lateral projection on each side, the TRANSVERSE PROCESS, to which the muscles are attached (W. f. 79, *tr*).

The vertebrae, composing the vertebral column, articulate with each other by means of ARTICULATING PROCESSES, or ZYGOPOPHYSES, which are developed both anteriorly and posteriorly on the neural arches (W. f. 79, *prez*). The anterior pair of processes of each vertebra, except the first, thus articulates with the posterior pair of the vertebra in

front. Thus the vertebral column is made up of a series of definite articulating units, the vertebrae, each of which, by means of the neural arch, contributes a portion of the common neural canal containing the spinal cord. The vertebral column, while giving a firm axial support, also permits a considerable amount of bending. The first vertebra possesses two modified articulating processes, consisting of two concavities, into which the convex prominences of the occipital condyles at the posterior end of the skull fit.

The structure of the vertebral column in the various Vertebrates is essentially the same, but the number of vertebrae present is subject to considerable variation (W. fs. 77, 81–87). In the Mammals, including Man, five regions are typically present, which, beginning at the anterior end, are known as the CERVICAL (neck region) (W. f. 81 B, *10*, *11*), THORACIC (chest region) (W. f. 81 B, *12*, *13*), LUMBAR (abdominal region) (W. f. 81 B, *15*, *16*), SACRAL (pelvic region) (W. f. 81 B, *17*), and CAUDAL (tail region). In the adult condition of Man there are 26 vertebrae in the vertebral column divided as follows: 7 cervical, 12 thoracic with a pair of ribs attached to each, 5 lumbar, 1 sacral, and 1 caudal (W. f. 186). In early life there are 33 vertebrae present. The reduction is due to a fusion of 5 sacral bones to form the one sacral of the adult, and a fusion of the 4 caudal bones to form one which is known as the COCCYX (W. f. 87, *26*). In all the Mammals, except Man and the Anthropoid Apes, the number of caudal vertebrae is quite large, thus in the Cat there are 22 caudal vertebrae (W. f. 81 B, *17*).

c. APPENDICULAR SKELETON. The appendicular skeleton consists of the fore and hind limbs, both of which are of the five-fingered, or PENTADACTYL, type; and the GIRDLES by which they are attached to the axial skeleton. The fore limbs are attached and supported by the PECTORAL GIRDLE and the STERNUM. The latter is the common ventral uniting structure for the two halves of the girdle, and also serves as a protection for various internal organs which lie in that

part of the body. Each half of the pectoral girdle is made up of a number of bones and cartilaginous elements; the principal ones being the SCAPULA, CLAVICLE, and CORACOID. The scapula and coracoid on each side form a cavity, the GLENOID FOSSA, into which the proximal end of the humerus (noted below) of the fore limb fits (W. fs. 80, A; 81 A).

The PELVIC GIRDLE, which forms the support and attachment of the hind limbs, consists of right and left halves, each formed from three bones, the ILIUM, ISCHIUM, and PUBIS; the ilium being the largest. The latter in the Frog, connects anteriorly with the transverse process of the ninth vertebra, continues posteriorly nearly parallel with the median urostyle at the posterior end of the vertebral column, and, finally, connects with the ischium and the pubis. The ischium and pubis, together with the posterior end of the ilium, form a common cavity, the ACETABULUM, on each side of the body into which the proximal end of the femur (noted below) of the hind limb fits (W. fs. 80, B; 81 A).

Each FORE LIMB consists, first, of a large bone, the HUMERUS, which, as has been noted above, articulates at its proximal end with the glenoid fossa of the pectoral girdle (W. f. 81 A, *hu*). The distal end of the humerus articulates with the RADIO-ULNA (W. f. 81 A, *ra. ul*). This is a single fused bone in the Frog, but in many of the Vertebrates it consists of two separate bones, the radius and ulna (W. f. 81 B, *31*, *32*). In the Frog there are six wrist, or CARPAL, bones, three of which articulate with the radio-ulna, and three which articulate with the bones of the hand. Each of the five digits of the hand begins proximally with a METACARPAL bone. In digit I, there is no other bone. In digits II and III, the metacarpals are followed by two PHALANGES, and in digits IV and V, the metacarpals are each followed by three phalanges, making a total, therefore, in the hand of the Frog of five metacarpal bones and ten phalanges. (W. fs. 80, A; 81 A.)

The HIND LIMB of the Frog and of Vertebrates in general

has practically the same structure as the fore limb. The names of the bones, however, are different. In the hind limb there is, first, a large FEMUR which corresponds to the humerus in the fore limb (W. f. 81 A, *fe*). It articulates proximally, as noted above, with the acetabulum of the pelvic girdle (W. f. 81 A, *act.b*). The distal end of the femur articulates with the TIBIO-FIBULA (W. f. 81 A, *ti*, *fi*). This is a single fused bone in the Frog, but in many of the Vertebrates it consists of two separate bones, the tibia and fibula (W. f. 81 B, *23*, *24*). It is homologous with the radio-ulna of the fore limb. The ankle bones of the Frog are quite atypical. Each of the five digits of the foot begins proximally with a METATARSAL bone. In digits I and II, there are two PHALANGES each; in digits III and V, there are three phalanges each; in digit IV, there are four phalanges, thus making in all a total of fourteen phalanges in the foot as compared with ten in the hand. Lying outside of digit I in the foot of the Frog is an accessory digit, the CALCAR, which is a spur-like structure formed from two small bones. (W. fs. 80, B; 81 A.)

d. THE VERTEBRATE LIMB.[1] The pentadactyl limbs of the Frog, the structure of which has just been considered, are essentially the same as, and are homologous with, those found in all the higher Vertebrates, including Man. The greatest amount of variation between various limbs takes place in the wrist and hand bones of the fore limb, and the ankle and foot bones of the hind limb; the larger bones situated nearer the body being somewhat more constant throughout the Vertebrate series (W. fs. 81 B, *18–35;* 185). Thus in the fore limb, or wing, of a Bird the humerus, radius, and ulna are all typical, but in the wrist and hand there has been a great reduction in the bones typically found there (W. f. 185, *A*). In the hoofed Mammals the structure of the limbs has departed more widely from the pentadactyl type than in any other Vertebrate (W. f. 185, *D*, *E*). Thus in the

[1] Woodruff, pp. 351–364.

fore limb of the Horse the humerus is about the only bone that still retains the typical structure (W. fs. 185, *E*; 189). Only a small portion of the ulna is present, and it is fused with the radius. Digits I and V have entirely disappeared. Digits II and IV are present as rudimentary structures, known as splint bones. Digit III remains as the sole functional digit, so that the Horse walks on the tip of the third digit. In Man, the limbs have remained true to the pentadactyl type, except that there has been a fusion of certain bones in the wrist and ankle (W. f. 185, *F*).

10. *Reproductive System*[1]

The sexes in Frogs are separate, but there is no great differentiation in the external structural characters between the male and female. The fore limbs of the male are somewhat heavier, and also the first digit of each hand is larger. During the breeding season in the spring this finger becomes swollen, and this makes it easier to differentiate between the two sexes at that time.

MALE REPRODUCTIVE ORGANS. The male organs of reproduction consist of a pair of TESTES in which the sperm are developed, and numerous fine ducts, known as the VASA EFFERENTIA, which convey the mature sperm cells from the testes to the urogenital canals (W. f. 83, *49*). Attached to each testis is a yellow FAT BODY (W. f. 83, *34*). The latter are not directly concerned in reproduction, but serve as storehouses for excess nutriment received during the summer season. Each testis is a light-colored, elongated, capsule-shaped body which lies on the ventral side and near the anterior end of each kidney, to which it is attached by the vasa efferentia. The latter extend directly through the tissue of each kidney and connect with the UROGENITAL CANAL, which leads from the lateral edge of each kidney to the cloaca (W. f. 83, *31*). The sperm cells leaving the testes

[1] Woodruff, pp. 203–208; 223–243.

pass through the vasa efferentia into the urogenital canals, which serve as common ducts for the wastes from the kidneys and the sperm from the testes.

A microscopic examination of the testis shows that it consists of a mass of greatly twisted tubules together with blood vessels, nerves, and connective tissue elements. The tubules open near the center of the testis into the vasa efferentia. The other end of each tubule is closed and lies near the outer wall of the testis. The sperm develop from the PRIMORDIAL GERM CELLS situated in the wall of the tubules (W. f. 125). The sperm cells are typical in structure at first, but after passing through the various stages (SPERMATAGONIA, SPERMATOCYTES, and SPERMATIDS) they become greatly modified bodies each of which is made up of (1) a pointed HEAD, containing nuclear material; (2) a MIDDLE PIECE, containing cytoplasm, chromatin material, and CENTROSOME, and (3) a long TAIL, which has an active, vibratory movement, and thus enables the sperm to move through a suitable liquid with considerable rapidity (W. f. 129, *B*).

FEMALE REPRODUCTIVE ORGANS. The female organs of reproduction consist of a pair of OVARIES in which the eggs are developed, and a pair of OVIDUCTS which carry the eggs to the cloaca. There is also a pair of FAT BODIES one of which is attached to each ovary. Each ovary is really a thin-walled sac with an outer covering which is a continuation of the peritoneum lining the entire body cavity. This outer covering is lined by a layer of GERMINAL EPITHELIUM in which the eggs arise. The eggs are more or less grouped in bunches and the ovary as a whole has a number of well-defined lobes. The organ is very plentifully supplied with blood vessels.

Each egg cell is enclosed by a thin cell wall (VITELLINE MEMBRANE) which is surrounded by several layers of specialized cells (MEMBRANA GRANULOSA). Each ovarian egg with the surrounding layers constitutes a GRAAFIAN FOLLICLE.

The eggs develop from cells which appear typical. They pass through various stages of development and gradually increase in size until they are several times the size of a somatic, or body cell. This increase results from the storage of a considerable amount of food material, and is a very common phenomenon in the eggs of most animals (W. f. 125). Except for its size, the mature egg shows a normal cell structure, and is, therefore, very different from the highly modified sperm cells. (W. fs. 7, A, B; 127; 129.)

The eggs of the Frog reach their full development at only one period in each year. This is in the early spring, at which time the two ovaries, distended with masses of eggs, fill up a large portion of the abdominal cavity. When the proper time arrives the eggs break through the thin ovarian wall and are drawn into the openings of the oviducts. There is no direct connection between the ovaries and the oviducts as in the case of the testes and the vasa efferentia.

Each of the coiled, tubular oviducts ends anteriorly in a ciliated, funnel-shaped opening. These openings lie in the anterior end of the coelom, one on either side and a considerable distance anterior to the ovaries. The action of the cilia in these openings is of such a character as to cause a current to flow into them, and thus the eggs are drawn into the oviducts. At the posterior end of each oviduct before it opens into the cloaca there is an enlarged portion. This is known as the UTERUS, and the eggs, after passing down the oviduct, collect in this region and remain there for a time before being discharged from the body. During their passage through the oviducts the eggs are coated with several layers of jelly which are secreted by glands in the walls of the oviducts.

The Frog's egg, when observed with the naked eye, appears as a tiny sphere composed of a dark-colored portion, termed the ANIMAL POLE, and a light-colored portion, termed the VEGETAL POLE. Each egg is enclosed in a transparent, vitelline membrane around which are the layers of jelly.

A microscopic study of prepared sections shows that the protoplasm of the egg is largely concentrated in the animal pole. This fact is emphasized by the position of the nucleus which lies approximately in the center of the animal pole. The vegetal pole contains a large proportion of non-living food material for use of the embryo during the early stages of development before it is able to take in food. (W. f. 134.)

XXII. VERTEBRATE DEVELOPMENT [1]

A. Development of the Frog

The sperm and the eggs of the Frog are both discharged directly into the water. The former by their active swimming movements reach the eggs and fertilization takes place. It is probable that the sperm are attracted by certain chemical substances given off by the eggs. In fertilization the nucleus of the egg and the nucleus of the sperm unite in the egg cell to form the synkaryon just as has been noted previously in the Invertebrates. If the eggs are not fertilized no development takes place, and disintegration occurs after they have been in the water for a while. When an egg has been fertilized the synkaryon prepares at once for mitotic cell division. A typical spindle is formed, and the egg soon divides into equal halves which remain close together within the vitelline membrane. (W. fs. 123–127.)

1. *Early Development*

Cleavage. In general, the animal pole of the Frog's egg divides more rapidly than the vegetal pole. The latter is retarded by the large proportion of inert food substances, or yolk, which are present in it. The early cleavages generally occur in a regular order which may be described as follows. The first plane of cleavage begins near the center of the animal pole and extends down through the vegetal pole, thus cutting the egg into equal halves, each of which is composed of a portion of both the animal and vegetal poles (W. f. 134, *A*). The second cleavage is at right angles to the first, but in the same direction so that the new embryo consists of four similar cells, each composed of material form both poles

[1] Woodruff, pp. 54–60; 249–260.

(W. f. 134, *B*). The plane of the third cleavage is at right angles to the first and second. It cuts the quadrants, previously formed, in the region which separates the animal pole from the vegetal pole. The resulting eight cells consist of an upper quartet of small dark-colored cells formed from the animal pole, and a lower quartet of large cells formed from the vegetal pole (W. f. 134, *C*). The fourth and fifth cleavages are parallel to the first and second, but between them. They both begin in the animal pole and slowly extend through the vegetal pole. The sixth cleavage is parallel to the third, but lies above it and is, therefore, entirely in the animal pole. After the sixth cleavage the divisions become more or less irregular. As a result of the more rapid division of the dark-colored cells of the animal pole, they are much smaller after a time than those of the vegetal pole (W. f. 134, *D*).

BLASTULA. At about the 24-cell stage the first indications are found of an internal cavity, termed the SEGMENTATION CAVITY, or BLASTOCOEL, situated well toward the animal pole of the egg (W. f. 134, *E*). As cleavage continues this segmentation cavity, as shown by a study of prepared sections, increases in size. It is enclosed above and on the sides by layers of the dark cells, and, in the same way, below by the larger white cells. Such a stage constitutes the BLASTULA of the Frog's egg, and it has the general external appearance of the golf ball with approximately one-half of the surface (animal pole) blackened (W. f. 134, *F*).

GASTRULA. Typically, as we have already learned, a GASTRULA is a two-layered sac formed by a direct invagination of a portion of the outer ectoderm to form an inner endoderm layer (W. f. 19, *G–I;* f. 69, *F*, *G*). In the Frog, however, owing to the large amount of yolk stored in the vegetal pole, the invagination of the ectoderm is considerably modified, and the two-layered gastrula stage is reached partly by an overgrowth and partly by an invagination of the dark cells. The comparatively rapid growth and division of the dark cells results in an actual overgrowth of the cells of the vegetal pole

so that, as the process proceeds, the light-colored area of the vegetal pole, as seen externally, constantly diminishes until, finally, only a tiny white area, the YOLK PLUG, remains (W. f. 134, *G*, *H*).

Coincident with the overgrowth there is a turning in, or invagination, of the outer dark ectoderm cells to form the two-layered gastrula. This process begins in a small crescent-shaped area lying near the boundary between the dark and white cells. The area of invagination soon becomes circular in outline, and then, as the growth over the white cells continues, contracts in diameter, finally reaching the stage noted above where only a tiny area of the white cells, the yolk plug, is visible externally (W. f. 134, *H*). The circular area of invagination is known as the BLASTOPORE. It indicates the posterior end of the embryo and marks the position of the future ANAL OPENING. The area, where invagination begins, is known as the DORSAL LIP of the blastopore. (W. f. 134, *I*, *blp*.)

Inside the embryo at this stage, largely as a result of the turning under, or invagination, of the outer ectoderm, a layer of ENDODERM is formed around the blastopore. It is thickest on the dorsal side and spreads laterally soon forming a definite layer beneath the ectoderm (W. f. 134, *I*, *end*). It obliterates the original blastocoel, and a new cavity is formed, lined by endoderm, which constitutes the primitive alimentary canal, or enteric cavity, of the embryo. It terminates posteriorly at the blastopore which, as mentioned above, marks approximately the position of the permanent anal opening. (W. f. 134, *I*, *ent;* *K*, *pcdm*.) The mouth opening is later formed at the anterior end of the alimentary canal (W. f. 134, *J*, *stdm*). During gastrulation the MESODERM is also forming in the region of the blastopore as a third layer between the ectoderm and endoderm. The three layers, ectoderm, endoderm, and mesoderm constitute the primary germ layers from which all the tissues and organs of the Frog develop (W. f. 134, *I*, *ect*, *end*, *mes*).

During the process of invagination, the layer of endoderm, which forms the dorsal wall of the enteric cavity, becomes thickened, and from it an axial rod of tissue, the NOTOCHORD, splits off (W. f. 134, *K*, *nch*). This is the forerunner of the segmented, bony vertebral column which later develops around the notochord. An external examination of an egg at about this stage, when the blastopore is nearly closed, shows a differentiation of the ectoderm on the dorsal side of the body to form the MEDULLARY FOLDS which are the forerunners of the central nervous system. The edges of the medullary plate, on either side of the median line of the embryo, become enlarged and somewhat elevated (W. f. 134, *H*, *J*). A little later the two edges, running almost the length of the body, meet above the midline and fuse, and thus a dorsal NEURAL TUBE of ectoderm is formed. From this ectodermal neural tube the differentiated brain and spinal cord later develop (W. f. 134, *K*, *sp. cd*).

2. *Later Development*

Synchronous with the formation of the central nervous system from the ectoderm, as just described, the embryo begins to lose the spherical shape of the original egg and to elongate in an anteroposterior axis so that the definite body regions can be identified. Anteriorly the head is indicated, and just back of it on each side of the body, the ectoderm becomes thickened and modified to form an elevated GILL PLATE through which lateral openings into the pharynx (GILL SLITS) later appear (W. f. 134, *J*, *br. cl*). Anterior to each gill plate, a swelling can be seen on the side of the head, which is the forerunner of certain sense organs. The ventral and posterior regions of the body are still very heavily loaded with yolk material at this time. Projecting from the extreme posterior end, on the dorsal side of the embryo, is the TAIL BUD which grows posteriorly to form the tail region. (W. f. 134, *J*, *t*.) A depression on the anterior ventral surface of

the head indicates the position of the future MOUTH, and a similar depression at the posterior end of the body, near the original blastopore, marks the future position of the ANUS. Just posterior to the mouth depression, a crescent-shaped area indicates the VENTRAL SUCKER. During all these changes the animal is not feeding, but is getting its nourishment from the utilization of the food materials which were stored in the vegetal pole of the egg. (W. f. 134, *J*, *stdm.*)

The microscopic examination of a longitudinal section, in a sagittal plane, through an embryo in the tail-bud stage shows the following condition. There is an outer covering of ectoderm cells (W. f. 134, *K*, *ect*). Lying ventral to the ectoderm on the dorsal side, is the neural tube, just formed by the fusion of a portion of the dorsal ectoderm (W. f. 134, *K*, *sp. cd*). The neural tube runs the entire length of the embryonic body and, at this stage, shows very little differentiation. At the anterior end of the embryo it curves ventrally, and the closed end lies in the ventral half of the body. The curved, anterior end of this tube differentiates into the fore-brain and the mid-brain; the hind-brain develops just posterior (W. f. 134, *K*, *f. br*, *m. br*, *h. br*). At the posterior end of the body, the neural tube also bends ventrally, and in that region its cavity connects for a time with the cavity of the enteron (W. f. 134, *K*, *n. e. c.*).

Lying ventral to the neural tube is the solid rod-like notochord (W. f. 134, *K*, *nch*), and below this the enteric cavity, the walls of which are composed of endodermal cells. It also runs the entire length of the body. In the head region the cavity of the enteron is very much larger than it is posteriorly. This enlarged portion constitutes the primitive PHARYNX (W. f. 134, *K*, *ent*). Various portions of the alimentary canal differentiate from it later. A projection of the pharynx runs posteriorly into the yolk mass, close to the ventral body wall. The LIVER is formed from this diverticulum, and it is consequently known as the LIVER DIVERTICULUM. Anterior to this, between the ventral wall of the pharynx and

the body wall, is a space which contains a few scattered, embryonic, mesoderm cells. These cells represent the rudiment of the future HEART (W. f. 134, *K*, *mes*).

Back of the pharynx, the enteron continues as an undifferentiated tube to the posterior end of the body where it communicates, as noted above, with the cavity of the neural tube. At this time the permanent anal opening has not been formed, but a little later it breaks through the body wall, just below the embryonic blastopore, and the temporary connection with the neural tube is also lost (W. f. 134, *K*, *pcdm*). A considerable mass of yolk material is present in the embryo at this stage. The cells containing this material are largely grouped in the posterior half of the embryo, between the ventral wall of the archenteron and the ventral wall of the embryo. By the time this food has been utilized, the mouth and anal openings have been formed and the embryo can begin to feed. (W. f. 134, *K*, *yk*.)

Lying on either side of the neural tube and notochord, in a somewhat triangular space, bounded externally by the ectoderm, is the mesodermal tissue. The mesoderm is first formed as two sheets of tissue running anteriorly from the blastopore, one on either side of the neural tube and notochord. They grow laterally and ventrally, and soon become separated, by a longitudinal division, into a dorsal portion (VERTEBRAL PLATE) and a ventral portion (LATERAL PLATE). The vertebral plates soon show evidence of segmentation, and divide transversely into a number of muscle segments, or MYOTOMES. The lateral plates of mesoderm grow ventrally and extend around the ventral half of the embryo until they meet and fuse in the mid-ventral line, thus forming a complete layer of mesoderm, just under the ectoderm and enclosing the endoderm. Before this process has been completed, each lateral plate splits into an outer layer, known as the SOMATIC LAYER, which is closely applied to the ectoderm of the body wall, and an inner layer, the SPLANCHNIC LAYER which encloses the endoderm of the enteron, and later

gives rise to the supporting and muscular elements of the wall of the alimentary canal (W. f. 69, *K; sm, spl. m*). Between the somatic layer and splanchnic layer a cavity develops which is the permanent body cavity, or COELOM (W. f. 69, *K, coe;* p. 127).

Rapid growth of the embryo continues and, in a few days after fertilization, a free-swimming, fish-like tadpole has developed with definite head, body, and tail. By this time the embryo has hatched, that is, it has emerged from the capsule of jelly enclosing it. The enteron has developed into a long, coiled intestine which is typical of herbivorous animals. External respiratory organs are present in the form of branched gills, which arise from each side of the head. These persist only a very short time and are replaced by internal gills, lying in the gill slits, which open in the pharynx. Definite sense organs (eye, nose, and ear) can be identified in the head region. The tail has grown posteriorly to a considerable length. Along each side of the body the primitive muscle segments, or myotomes, as noted, can be seen lying below the outer ectodermal covering. Limbs are not present at this time.

DERIVATION OF THE ORGANS. As already noted, all the tissues and organs of the Frog develop from the three primary germ layers (W. pp. 57–58). The tissues derived from the ECTODERM include the epidermis which forms the outer covering over the entire body, also the central nervous system with all of its later developments.

The ENDODERM gives rise to the wall of the primitive enteric cavity. This wall remains as the permanent lining of the alimentary canal so that, even in the adult condition, the alimentary canal is lined for almost its entire length by cells which have been derived from the endoderm. There is a portion of the mouth cavity (STOMADEUM) where the ectoderm is slightly invaginated, and also a region at the extreme posterior end (PROCTADEUM) of the alimentary canal where the same condition prevails (W. f. 134, *K, pcdm*). In addi-

tion to lining the alimentary canal, the endoderm cells also form a number of organs which develop originally as outgrowths from the alimentary canal. These associated organs all form in much the same way by an outpocketing of the endodermal wall of the enteron to form either single or paired structures which later differentiate into various organs, such as the lungs, thyroid glands, liver, pancreas, and bladder (W. f. 88).

From the important MESODERM layer is formed the muscular, vascular, and supporting elements of the body. Previous mention has been made of the division of the mesoderm into the vertebral and lateral plates. The myotomes of the former, together with the somatic layer of the lateral plates, give rise to the muscle tissue of the body wall and appendages, together with the connective tissues, vascular elements, etc.; while the muscle layers, and other elements of the wall of the alimentary canal, except the endodermal lining, are derived from the splanchnic layer (W. pp. 138–39). The coelom is lined with peritoneum which is continuous over the alimentary canal and other organs, and is derived from both the somatic and splanchnic layers. The peritoneum forms the mesenteries by which various organs are attached to, and suspended from, the walls of the coelom (W. f. 83, *12*). The mesoderm also gives rise, for the most part, to the urogenital system.

The fact should be emphasized that the organs, in general, are not formed from a single tissue, but, on the contrary, represent a mosaic of various tissues. The liver, for example, is fundamentally an endodermal organ, but not exclusively so, for it contains vascular and connective and nervous elements derived from both the mesoderm and ectoderm.

3. *Metamorphosis*

After a period of time, the length of which shows a great deal of variation among different species of Frogs, the fish-like larva, or tadpole, undergoes radical changes both in

structure and habits. These changes constitute a process of METAMORPHOSIS, and result in the formation of an air-breathing, adult Frog with two pairs of limbs and no tail. Experimental work in recent years has shown that the process of metamorphosis in the Frog, is controlled to a great extent by hormones secreted by the thyroid glands (p. 203). The chief changes which occur during metamorphosis may now be noted:

(1) In the development of limbs, swellings appear, one on either side of the body at the base of the tail. These are the posterior LIMB BUDS, and they continue to grow rapidly and soon form the hind limbs. The fore limbs, which develop later, are formed from the body wall in the region of the gills. If the operculum (p. 250) is cut away in this region at the proper time, the tiny limbs may be found one on either side. Before metamorphosis is completed the fore limbs break through the operculum, so that at this stage we have a creature with two pairs of limbs and also with a long tail.

(2) Shortly after the appearance of the fore limbs, the tail begins to decrease in size, and this process continues until, by the time metamorphosis is completed, it is entirely resorbed. It is not clear as to just how these degenerative changes in the tail are brought about.

(3) During metamorphosis, great changes take place in the alimentary canal. In the tadpole, this structure is very long and coiled and without much differentiation between the various regions. Such a type of alimentary tract is adapted for securing nourishment from plant tissues which form the greater part of the food of the tadpole. The metamorphic changes cause a great decrease in the length of the tract, and a greater degree of differentiation between the various regions. These structural changes adapt the alimentary canal for the digestion of animal tissues which form the greater part of the food of the adult Frog.

(4) During metamorphosis the lungs, which started to develop very early in the embryonic life and then stopped,

begin their growth anew and form a pair of elongated, distensible, tubular sacs with highly vascularized walls. They lie, as we know, in the anterior end of the coelom, and are connected, by the tracheae, with the glottis which opens in the ventral wall of the mouth (W. f. 83, *23*, *24*, *26*). Coincident with the development and functioning of the lungs, the internal gills begin to degenerate, and the young Frog is no longer able to secure oxygen from the water, but must come to the surface and inhale air directly into the lungs, so that the haemoglobin of the blood can carry on the respiratory interchange. These changes having been completed, the young Frog is like the adult, except that it is smaller. It feeds and soon attains the adult condition.

4. *Life Processes in the Frog Embryo*

As soon as an egg is fertilized by a sperm it is an embryo of a new generation, in other words, a living organism, and as such it must carry on the essential life processes if it is to survive. It will be of value at this point to indicate briefly how the Frog embryo is able to do this. In the first place, the question of nutrition must be considered. The process of cell division and all the other developmental phenomena require energy. This energy in the early stages, up till the time when the alimentary tract is completed by the mouth and anal openings, is obtained by the embryo from the yolk material present in the egg, the presence of which in the vegetal pole has already been noted. As a matter of fact, the yolk material is scattered to a greater or less degree all through the egg, and in the succeeding cell divisions this food material is passed on to all the cells.

After the embryo has hatched from the egg jelly it begins to swim vigorously. Soon after this, the alimentary tract is completed, and the animal begins to ingest food. It is adapted for plant feeding, and considerable quantities of plant tissues are eaten. It is aided in feeding by a special

organ, the VENTRAL SUCKER, just posterior to the mouth, which enables the tadpole to remain attached to a plant in the water and feed undisturbed.

From the one-celled condition until sometime after the tail-bud stage, the embryo does not possess a vascular system. Inasmuch as the food material is scattered among the cells there is no general problem with regard to the transportation of food. The food is concentrated to the greatest extent in the middle of the body, ventral to the archenteron and posterior to the pharynx. Apparently the excess of food in these cells is passed on to the other cells of the embryo just as in Hydra and other Coelenterates where no vascular system ever develops. (W. f. 134, *K*, *yk.*)

Respiration must, of course, be continuous from the earliest stages. At first this respiratory interchange takes place at the surface of the embryo, through the jelly capsule. This method does not long suffice, and coincident with the establishment of the vascular system, gills are formed through which the interchange of gases takes place. External gills are present for a few days. Later they are covered by a fold of ectoderm (OPERCULUM), and internal gills develop in the walls of the gill slits. In this condition, water is drawn in the mouth and forced out through the lateral gill slits in the pharynx where it comes into contact with the gill filaments (W. f. 94). This latter method of respiration is continued until the lungs are developed, after which the animal breathes air. The gills on the right side of the embryo degenerate first.

Excretion of urea in the tadpole is carried on in the early larval stages by tubular organs, known as the PRONEPHROI. A pair of these is developed very early, one on either side of the body. Each pronephros consists of three tubules which open into the coelom at one end. They unite at the other end to form the common PRONEPHRIC DUCT. These ducts run posteriorly on each side of the body into the cloaca (W. f. 97, *A*).

The anterior portion of each pronephric duct degenerates in later larval life, and a group of tubules develop posteriorly on each side of the body (W. f. 97, *B*). These form the permanent kidneys, or MESONEPHROI, of the Frog which open into the posterior part of the former pronephric ducts. The latter remain as the permanent ducts (W. f. 97, *C*, *D*). In the higher Vertebrates, the permanent kidneys develop later, and are known as the METANEPHROI (W. pp. 176–178; f. 97, *E*, *F*).

B. Development of the Chick

The male and female reproductive organs of the Birds have the same fundamental type of structure that is found in the Frog and other Vertebrate animals. They are paired structures in their early development, but, in the later stages, the organs on the right side of the female undergo degeneration so that the functional reproductive organs in the female are present only on the left side.

The OVARY, as seen with the naked eye, consists of a mass of various sized eggs which appear as yellowish globules. The ovary is suspended from the dorsal wall of the abdomen by a connective tissue mesentery, known as the MESOVARIUM. Lying near the ovary is a large, glandular OVIDUCT which ends anteriorly, as in the Frog, in a large ciliated opening, the OSTIUM, and connects posteriorly with the cloaca. The oviduct consists of three portions: (1) the OSTIUM, which is followed by (2) a GLANDULAR PORTION, the cellular walls of which secrete both the 'white' of the egg and the shell, and (3) a THIN-WALLED PORTION, which opens into the cloaca.

The portion of the Hen's egg corresponding to an entire Frog's egg is the so-called yolk. In the early stages of development in the ovary, the egg cells are normal in size and shape. During the developmental stages a considerable amount of food material is deposited in each of the cells which are to develop into mature eggs, so that they rapidly

increase in size. There is a certain rhythm in egg formation. The Hen will lay an egg a day for some two or three weeks, and then will come a period of cessation during which the clutch of eggs can be incubated. This will be followed by another period of egg laying.

The large amount of food material present in the yolk crowds the egg nucleus to the surface of one pole, where it can be seen in a mature egg as a little, white, circular area, the BLASTODERM (W. f. 128, *bl*). The remainder of the cell outside of this small blastoderm, consists chiefly of inert food material. This condition is an exaggeration of that found in the Frog's egg where the greater proportion of the protoplasm is at the animal pole and the greater proportion of food materials is at the vegetal pole. At this stage the egg cell, or, as we commonly term it, the yolk, bursts forth from the ovary, is taken into the ostium, and begins its passage to the exterior through the oviduct. Normally, in the upper end of the oviduct, the egg cell comes into contact with the sperm, which were placed in the lower end of the oviduct by the male. After fertilization, the division of the blastoderm begins. The blastoderm of the Hen's egg is the only part of the cell that divides. Thus we have partial, or MEROBLASTIC, cleavage in the Hen's egg as compared with total, or HOLOBLASTIC, cleavage in the Frog's egg.

The fertilized egg continues its passage down the oviduct, and the cells in the anterior glandular portion of the oviduct secrete several layers of ALBUMEN, or 'white,' around it (W. f. 128, *alb*, *alb'*; *ch*). Farther posterior other secreting cells form a thin, enclosing membrane which lies just below the shell in the Hen's egg (W. f. 128, *sh. m*). Still farther down the oviduct other secreting cells give off a material which forms the outer EGG SHELL (W. f. 128, *sh*). The latter is largely composed of lime, or calcium carbonate. The passage through the oviduct usually takes 24 hours, so that if it is fertilized in the anterior end of the oviduct, it has reached the 24-hour stage development at the time that it

is laid. When the egg is laid, development ceases unless the proper temperature (38° C.) is again supplied. The embryo of the egg will remain dormant without injury for several days and then start to develop again when given the proper temperature.

The division of the blastoderm in the Hen's egg after fertilization results in the formation of a great number of irregularly-shaped cells which lie at the center of the blastoderm. These are the primitive ectoderm cells, and they soon form a few layers of cells which overlie a small cavity on the surface of the yolk, which is the BLASTOCOEL, or SEGMENTATION CAVITY. This constitutes the blastula stage of the Chick embryo, and it consists of flattened layers of ectoderm cells above the blastocoel, rather than a hollow sphere of cells enclosing the blastocoel as in the Frog.

The ectoderm cells continue to divide and very soon, in the region which is to become the posterior end of the embryo, they begin to turn under and form a two-layered, or GASTRULA, condition. The two layers extend anteriorly and laterally, and in a short time cover most of the blastodermic area. A median thickening appears in the blastoderm at about the eighteenth hour of incubation. This is known as the PRIMITIVE STREAK, and it indicates the longitudinal axis of the animal. The ectoderm and endoderm are in contact along the primitive streak, and it is also in this region that the mesoderm layer arises. The first mesoderm cells are given off in the posterior part of the primitive streak, but they soon spread laterally and anteriorly, forming a definite sheet between the ectoderm and endoderm.

At the anterior end of the primitive streak, the ectoderm cells divide very rapidly, and a definite anterior thickening can soon be observed in this region, known as the HEAD PROCESS. It consists at first of only the ectoderm and endoderm layers, but later the mesoderm is also drawn into it. The region of the blastoderm in which the head process forms, *i.e.*, just anterior to the primitive streak, contains the rudi-

ments of the body of the future embryo. Very shortly there is an anteroposterior thickening of the dorsal ectoderm in this region to form the rudiment of the central nervous system. This corresponds to the medullary plate stage in the Frog, and similarly there is an elevation of the lateral edges of the medullary plate and a fusion in the mid-line to form the neural tube. Lying below it will be found the endodermal notochord. The lateral mesoderm segments into the myotomes, which, as in the Frog, differentiate into dorsal and lateral portions. The latter splits into the outer somatic layer and inner splanchnic layer between which is the coelom.

All this time the young embryo, developing in the area of the blastoderm, is lying flat on the surface of the yolk. There now begins, at about the twentieth hour of incubation, a process of folding, first at the anterior end (HEAD FOLD), later at the sides (LATERAL FOLDS), and then posteriorly (TAIL FOLD), which results in an almost complete separation of the embryo from the yolk material, so that the latter after a time is attached to the embryo only by the yolk stalk, through which the food material is transported to the young embryo by the embryonic vascular system.

One of the distinctive things about the development of the Chick as compared with the Frog is that, owing to the position of the blastoderm which is spread out flat upon the surface of the yolk, the rudiments of the various structures such as the coelom, heart, alimentary canal, etc., are formed on either side of the embryo proper in right and left halves. These are located in the outlying or, as they are termed, EXTRA-EMBRYONIC REGIONS of the blastoderm. The process of folding off the embryo from the underlying yolk, which has been noted above, brings the right and left rudiments of these organs together, underneath the embryo, where they unite in a median ventral line to form the definitive organs.

By the end of the third day of incubation, the embryo has grown to a considerable size, and many of the organs are well

established. At this stage the entire animal is covered by a FOETAL MEMBRANE, the AMNION, which, starting anterior to the embryo in the ectoderm, has grown back over the animal from the anterior end and also to some extent from the posterior end, with the result that the embryo is enclosed in a definite sac (AMNIOTIC CAVITY). At this stage of incubation, the embryo does not have a straight, anteroposterior axis, but the anterior end has a twist (CERVICAL FLEXURE) of almost 90 degrees toward the right (W. f. 191, *B*). The central nervous system is well-developed, together with the sense organs such as the eye, nose, and ear. The vascular system is also well established and functioning. The heart at this time consists of an auricle and ventricle. The auricle receives the blood, containing food material, which has come in from the yolk sac through the large vitelline veins. This blood passes into the ventricle, and then it is forced out through the arteries to all parts of the growing body, and eventually back to the yolk sac. The embryo, at this stage, has four pairs of gill slits which are similar in structure to those formed in the lower Vertebrates. In the Chick, however, the gills never develop so as to function and, after a few days, disappear (W. f. 191, *B*, *g*).

The Chick embryo continues to develop, receiving its food from the yolk and carrying on respiration through the surface of the shell by means of the vascular system. The early development of the Chick requires about 21 days of incubation, and then it breaks through the shell, with the aid of a specialized structure which develops on the beak, and comes forth as an active animal able to secure its nourishment, and thus to continue its growth until the adult condition is reached.

C. THE DEVELOPMENT OF THE MAMMAL [1]

The Prototheria, such as the Duck-bill and Echidna, constitute the lowest group of the Mammals. It is noteworthy

[1] Woodruff, pp. 205–206.

that in this group of Mammals the females are oviparous, that is to say, they lay eggs which develop outside the body of the female. These eggs are similar to the large yolked eggs of the Birds and Reptiles (W. p. 416).

In the Metatheria and Eutheria the females are viviparous, that is to say, the fertilized eggs are retained within the body of the female in a specialized portion of the oviducts, known as the UTERUS, or WOMB, until the embryos reach a certain stage of development, at which time they are, as we say, born. The degree of development of the embryo at birth varies a great deal in the different species. In the Metatherian Mammals, such as the Kangaroo and the Opossum, the young are born in a very immature and helpless condition, and are placed by the mother, directly after birth, in a special sac, the MARSUPIUM, which is present in these Mammals on the ventral abdominal wall of the female. Here the embryos are nourished by milk from the mammary glands until they reach a sufficient degree of maturity to take care of themselves. Even among the Eutherian Mammals the development of the embryo at birth shows great variation in the different classes. Thus the new-born embryo is very well-developed among the hoofed Mammals, or Ungulates, while among the Primates, including Man, the young are born in a comparatively helpless and immature condition.

Except in the Prototheria, the mammalian egg, quite unlike that of the Frog and Chick, is very small, being in general microscopic in size, and contains practically no stored food for the nourishment of the embryo during the early stages of development (W. p. 238; fs. 7, A, B; 127; 129). It is therefore necessary, in order for development to proceed, that the fertilized egg receive nourishment from the maternal tissues very soon after development begins. This is supplied as described below.

If sperm are present the egg is fertilized soon after it enters the oviduct. It then begins to divide by mitosis. The cleavage is holoblastic and soon results in the formation

of a spherical body of cells, known as a MORULA. Except for the complete cleavage, the early development of the mammalian egg, including the formation of the various organs, shows great similarity to that of the Chick. A particularly noteworthy feature of the mammalian embryo at this stage is the precocious formation of the primary germ layers and the foetal membranes such as the amnion. A study of the structure of the embryo at the morula stage shows that the cells are differentiated into an INNER CELL MASS, which contains the rudiments of the embryonic body proper, and an outer layer, known as the TROPHOBLAST, which develops from the ectoderm at the surface and encloses the inner cell mass.

During the cleavage stages the embryo is passing through the oviducts down into the uterus, where it is to be attached and retained for a time during development. By the time it reaches the uterus the outer covering of trophoblast has been formed. This layer is very essential to the developing embryo, for the cells of which it is composed are able to secrete a ferment which erodes the small portion of maternal tissue lining the uterus with which the tiny embryo is in contact. Thus the embryo attaches itself to the mother, becoming actually embedded in the uterine wall. Nutritive materials are temporarily secured by the digestive and absorptive action of the trophoblast. A little later, by a combination of certain foetal tissues with a portion of the maternal uterine wall, a very remarkable mammalian structure, known as the PLACENTA, is formed (W. f. 113, *b*).

The placenta is the organ by means of which the essential interchange of materials between the embryo and the mother takes place. Certain large arteries of the mother bring maternal blood, carrying nutritive materials and oxygen, to the placenta, where it flows into large open sinuses. Here the maternal blood bathes certain process, or VILLI, which are formed from foetal tissue. The foetal villi contain the endings of the foetal blood vessels which run through the

UMBILICAL CORD (W. f. 113, *i*) and connect with the vascular system of the embryo. One of the foetal vessels (UMBILICAL ARTERY) brings blood to the placenta from the embryo. This blood contains nitrogenous wastes and carbon dioxide given off by the embryo. During the passage through the capillary network in the placenta these wastes are given off through the walls of the villi, into the maternal blood, and, synchronously, nutritive materials and oxygen are received from the maternal blood. The foetal blood, now freed from the wastes and containing the substances necessary for the embryo, passes into the UMBILICAL VEINS which carry it out of the placenta and back to the embryo through the umbilical cord. It should be emphasized that the vascular systems of the mother and embryo are not directly connected in the placenta or elsewhere — all interchange of materials between the mother and the developing embryo in the uterus must, therefore, take place by diffusion through the walls of the foetal villi in the placenta.

PART II

LABORATORY DIRECTIONS

I am impressed with the fact that the greatest thing a human soul ever does in the world is to see something, and tell what it saw in a plain way. Hundreds of people can talk for one who can think, but thousands can think for one who can see.

— *Emerson*

The invention of the microscope made small things seem large, and revealed to sight what was too small to be seen without it; but the use of magnifying glasses brought an advantage with it of a different kind — it taught those who used them to see scientifically and exactly. In arming the eye with these increased powers the attention was concentrated on definite points in the object; what was seen was to some extent indistinct, and always only a small part of the whole object; perception by means of the optic nerve had to be accompanied by conscious and intense reflection, in order to make the object, which is observed in part only with the magnifying glass, clear to the mental eye in all the relations of the parts to one another and to the whole. Thus the eye armed with the microscope became itself a scientific instrument, which no longer hurried lightly over the object, but was subjected to severe discipline by the mind of the observer and kept to methodical work. The philosopher Christian Wolff observed very truly in 1721, that an object once seen with the microscope can often be distinguished afterwards with the naked eye; and this, which is the experience of every microscopist, is sufficient evidence of the effect of the instrument in educating and training the eye.

— *Sachs*

INTRODUCTION

A. Equipment [1]

Each student will require the following equipment for his laboratory work:

(1) Text-books.
(2) Loose-leaf notebook, about $8\frac{1}{2} \times 10\frac{3}{4}$ inches, with white drawing paper.
(3) Dissecting instruments, consisting of scalpel, scissors, small forceps, two needles in holders, and ruler.
(4) Two pencils for drawing — 3H and 6H — and an eraser.
(5) Compound microscope with two eyepieces and two objectives.
(6) Dissecting microscope with one lens.
(7) Six glass slides.
(8) Twelve cover glasses.
(9) Lens paper.
(10) Filter paper.
(11) Piece of cheese cloth.
(12) Pins.

B. The Use and Care of the Compound Microscope

1. The compound microscope is a delicate, complicated, and expensive instrument and must always be handled with great care. It consists of the following parts:

(1) The BASE and UPRIGHT SUPPORT.
(2) The STAGE, with a CENTRAL OPENING which contains an IRIS DIAPHRAGM for regulating the amount of light. A CONDENSER is also present on some instruments.

[1] The instructor will indicate which items in the equipment are to be supplied by the student.

(3) The MIRROR, with concave and plane surfaces, which is attached underneath the stage.

(4) The BODY, with COARSE and FINE ADJUSTMENTS for focusing, DRAW TUBE, EYEPIECE, or OCULAR, and revolving NOSEPIECE holding the OBJECTIVES.

Identify each of these parts and learn how they are used.

2. Each day before using the microscope, see that all parts are clean. Be sure that they are kept clean during the exercise and that the instrument is clean when you leave. If you find the instrument dirty or in bad order, report it at once to the instructor in charge of the room. Lens paper is furnished for cleaning the lenses, and it is not permissible under any circumstances to clean the lenses with any other material.

3. Place the microscope in position, with the upright support toward you. See that eyepiece No.[1] and objective No.[1] are in position and that the iris diaphragm is open. Adjust the mirror so that the maximum amount of light will be reflected up through the central opening of the stage. In general, use the mirror with the concave surface up.

4. Place the glass slide, on which the object to be examined is mounted, upon the stage with the object directly over the central opening. Carefully turn the coarse adjustment screw away from you until the end of the objective is approximately one-fourth of an inch from the upper surface of the slide. Then, while looking through the eyepiece, slowly turn the coarse adjustment screw toward you until the object comes into view. Bring the image into an exact focus by slowly turning the fine adjustment screw in either direction, as may be necessary. Never focus downward with the coarse adjustment while looking through the microscope. It is less tiring and better in every way to keep both eyes open while looking through the microscope. You will be able to do this with a little practice.

5. Always find an object first with the lowest magnification, as described in the preceding paragraph, and always use the lowest magnification possible to accomplish the work in hand. Before changing from a lower to a higher power, always see that the ob-

[1] The numbers are different in the various makes of microscopes. The correct numbers for your microscope will be supplied by the instructor.

ject is exactly in the center of the field. The magnification may then be increased as desired in the following ways:

(1) By replacing eyepiece No.[1] with eyepiece No.[1]
(2) By replacing objective No.[1] with objective No.[1] This is accomplished by revolving the nosepiece. Inasmuch as this objective when in focus is very close to the upper surface of the preparation, it will be necessary to use great care in making this change.
(3) By doing both (1) and (2).
(4) The magnification can be still further increased by extending the draw tube, but this method is rarely used.

The approximate magnifications afforded by the various combinations are as follows:

Eyepiece[1]	×	objective	=	diameters	magnification.
"	×	"	=	"	"
"	×	"	=	"	"
"	×	"	=	"	"

When a very low magnification is desired, as for example in the study of a large opaque object, the simple DISSECTING MICROSCOPE is used. It gives a magnification of about 10 diameters.

6. At the close of each exercise be sure to remove, from the stage of the microscope, the slide that you have been studying. Examine the microscope carefully and make sure that all parts, including the lenses, are perfectly clean, and then return the microscope to its proper place in the case. Remember that since there are others who must use the same microscope, the welfare of the laboratory depends upon your coöperation in keeping the apparatus in order.

C. MICROSCOPIC PREPARATIONS

7. The objects which will be examined with the compound microscope may be divided into two classes as follows:

(1) PERMANENT MOUNTS in which the material to be examined has been previously subjected to complicated histological methods of preparation. Great care must be observed in handling these preparations. A charge will be made for breakage.

[1] Numbers will be supplied by the instructor.

(2) Temporary mounts which you will make from time to time from fresh materials according to the following directions:

(*a*) Thoroughly clean a glass slide and cover glass.

(*b*) Place a small drop of water in the center of the glass slide.

(*c*) Place the object to be examined in the drop of water.

(*d*) Cover the drop of water containing the object with the cover glass.

(*e*) Remove any superfluous water remaining around the cover glass with the absorbent filter paper. Be sure that no water gets on to the upper surface of the cover glass. The preparation is now ready to be studied under the microscope.

(*f*) When you have finished your study of the preparation, clean the slide and cover, and replace them in the drawer for future use.

D. Laboratory Drawings

8. It is essential that careful attention be paid to the following rules for laboratory drawings:

(1) Draw on only one side of the paper.

(2) Arrange the drawings as neatly and evenly on the page as possible, giving each plenty of space.

(3) Leave at least an inch margin around the edges of the sheet.

(4) Always label every drawing and each of its parts.

(5) Remember particularly that accuracy and neatness are two of the most important factors in good laboratory work.

(6) See that the laboratory room number, the seat number, and your name and class are placed on the upper right hand corner of each sheet of drawings.

(7) The drawings should be placed in a loose-leaf notebook. The direction sheets are perforated along the left edge so that, if desired, one can be removed for each exercise and mounted in the loose-leaf notebook opposite the sheet with the day's drawings.

PRELIMINARY MICROSCOPIC WORK

A. Dissecting Microscope

1. Examine, with the dissecting microscope, a slide on which a printed word has been permanently mounted. What apparent movement results when the slide is moved to the right? To the left? When it is moved toward, and away from you? When it is rotated?

B. Compound Microscope

2. After having carefully studied the previous section on "The Use and Care of the Compound Microscope," examine, with the lowest power of the compound microscope, a letter from the preparation you have been studying. What apparent movement results when the slide is moved to the right? To the left? When it is moved toward and away from you? When it is rotated? Draw this letter in its apparent position and magnification.

3. Replace the low-power eyepiece No.[1] with the high-power eyepiece No.[1] Draw the letter.

4. Replace the high-power eyepiece No.[1] with the low-power eyepiece No.[1] and, by revolving the nosepiece, replace the low-power objective No.[1] with the high-power objective No.[1] Carefully refocus with the fine adjustment. Draw the letter.

5. Without disturbing the objectives replace the low-power eyepiece with the high-power eyepiece. Draw the letter.

6. Note that the magnification can be still further increased by extending the draw tube. Extend it to its full length and, after refocusing, note the effect on the magnification.

7. Examine, with the low power, a preparation of scales from the wing of a butterfly. Make several outline drawings showing different types of scales.

8. Replace the low-power eyepiece with the high-power eyepiece. Study the markings on the surface of the scales and make a drawing of a portion of a scale to show their character.

[1] Instructor will supply information.

THE CELLULAR ORGANIZATION OF PLANT TISSUES

1. Carefully peel off, with a scalpel, a portion of the delicate, transparent covering (EPIDERMIS) from the upper surface of a leaf, and make a temporary mount, according to the directions in the previous section on "Microscopic Preparations." Examine the preparation with the low power of the microscope and draw about ten adjacent EPIDERMAL CELLS to show their structure and arrangement. Each cell should be drawn about half an inch in diameter.

2. Examine, with the low power, a permanent preparation of stained sections of an Onion root. Note that some of the sections are cut transversely and that others are cut longitudinally.

3. Study first a *transverse* section. These are circular in outline. Note the faintly stained, granular CYTOPLASM which surrounds the NUCLEUS of each cell and fills the greater part of the space within the CELL WALL. Note the VACUOLE present in some of the cells.

4. Draw about 10 adjacent cells to show their structure and arrangement. Each cell should be drawn about half an inch in diameter.

5. Draw, under the high power, a single cell about an inch in diameter, showing CELL WALL, CYTOPLASM, NUCLEUS, and VACUOLE.

6. Study a *longitudinal* section of the Onion root. Select a typical cell from near the tip of the root and make a drawing of it similar to that already made in paragraph 5.

7. Compare the last two drawings of cells in paragraphs 5 and 6 and from them make an outline, in perspective, of a single cell which will show it as a solid with the three dimensions.

THE CELLULAR ORGANIZATION OF ANIMAL TISSUES

1. Mount a small piece of the shed outer layer (EPIDERMIS) of Frog skin, which has previously been stained with eosin in water. Examine, with both the low and the high power, and draw about 10 adjacent cells to show their structure and arrangement.

2. With the handle of the scalpel, or the end of your finger, *gently* scrape the inside of your cheek. Mount the scrapings in a drop of water on a clean slide and examine with both the low and the high power. Draw, under high power, several cells of different shapes.

3. Stain the cells by adding a drop of acetic carmine. Examine under the high power and observe the changes which have taken place. It will be noted that the NUCLEUS of a cell stains more heavily than the cytoplasm. Make a drawing, about an inch in diameter, of a single cell showing the structure of the cytoplasm and nucleus.

4. Examine a permanent preparation of the liver or other tissue of an animal and draw several of the cells as seen under the high power, showing their structure in detail.

5. Mount a drop of Frog's blood which has been diluted with normal salt solution. Study under the low power and note the appearance of the disc-shaped cells (RED CORPUSCLES) floating in the plasma.

6. Examine the preparation with the high power, gently tapping the cover glass from time to time in order to set the cells in motion so that you may see their three dimensions. Draw three or four cells as seen from various aspects.

PROTOPLASMIC MOVEMENT

1. Mount two or three young leaves from near the tip of a stem of Elodea. Examine under the low power and draw a portion of one leaf to show the general structure.

2. Examine the preparation with the high power and find an area in which the cells show a movement of their contents. Carefully study the nature of the movement. Does the substance move in the same direction in all the cells? Does it change its direction after a time? Do any of the green, disc-shaped CHLOROPLASTIDS pass through the walls between adjacent cells? What is their course? Draw several adjacent cells and indicate by arrows the direction of the movement observed.

3. Stain the preparation with iodine solution. Make a large drawing of a cell to show CELL WALL, CYTOPLASM, NUCLEUS, CHLOROPLASTIDS, and VACUOLE.

4. Examine a few filaments of Oscillatoria under the high power, and make a diagram to illustrate the nature of the movement observed.

5. Observe the movements shown on the stimulation of the Sensitive Plant (*Mimosa pudica*).

6. Place a small piece of a Clam's gill on a slide and, with two needles, gently tease it apart in a drop of the body fluid. Cover and examine with high power. Note the currents in the surrounding fluid caused by the rapid vibration of the delicate, protoplasmic processes (CILIA) which are present on the outer, exposed surface of certain cells (CILIATED CELLS) of the gills.

7. To demonstrate the fact that lifeless particles may also exhibit motion, examine, with the high power, a drop of water which contains a little powdered carmine. The motion observed is termed BROWNIAN MOVEMENT.

AMOEBA

1. Mount and examine with a medium power (high-power eyepiece with low-power objective) a drop of water which contains Amoebae. These will be noted as very small, irregular, semitransparent, granular bodies. Study under high power, taking care not to lose the specimen when shifting objectives. Note: (1) the method by which the animal moves; (2) the constant but slow changes in the shape of the body, and (3) the irregular processes (PSEUDOPODIA) which are formed.

2. Distinguish the transparent, outer layer of protoplasm (ECTOPLASM) from the inner, granular layer (ENDOPLASM). In this connection, examine the pseudopodia with particular care.

3. Make at least 10 outline drawings, at one-minute intervals, to show the changes in the shape of the organism. Indicate in each drawing the anterior and the posterior end of the animal.

4. Note the food materials in process of digestion enclosed in the FOOD, or GASTRIC, VACUOLES in the endoplasm. If carefully watched it is sometimes possible to observe the manner in which an Amoeba ingests food and egests the indigestible refuse.

5. Locate the transparent, spherical CONTRACTILE VACUOLE and note that the fluid contents are discharged at intervals. Find the transparent, disc-shaped NUCLEUS.

6. Make a drawing, 2 or 3 inches in diameter, of an animal to show all of the details of structure which you have observed in your preparation.

PLEUROCOCCUS

1. Examine, with the dissecting microscope, the greenish material present on the outside of a piece of bark and note its general appearance.

2. Scrape off a little of the material on to a slide. Mount in a drop of water and examine with the low power of the compound microscope. Note that the material consists of definite cells, each of which is an independent unicellular plant, Pleurococcus.

3. Examine the preparation with the high power. Select a large single cell and note: (1) the CELL WALL, which is quite thick and composed of cellulose, and (2) the large green CHLOROPLASTIDS which almost fill the body of the cell. They are embedded in (3) the CYTOPLASM. (4) The NUCLEUS lies in the center of the cell between the chloroplastids, but is often somewhat difficult to demonstrate. Stain the preparation with iodine solution and reëxamine for the nucleus. Make a drawing of a single cell, about one inch in diameter, to show the structures observed.

4. Note that, in some cases, the cells may be in pairs or even in larger groups, both of which have resulted from the incomplete division of single cells. Thus small temporary colonies of independent cells are formed which are believed to be the forerunners of the permanent cell groupings in the higher multicellular plants and animals. Draw all the different kinds of cell-groups you can find in your preparation.

EUGLENA

1. Mount a drop of water containing Euglena, and examine with the low power. The active specimens will be seen as green, elongated, free-swimming bodies. When an individual is not actively swimming, it shows certain characteristic squirming movements (EUGLENOID MOVEMENTS) which result in marked changes in the shape of the cell.

2. Make a series of outline drawings to show the successive changes in the shape of a single individual.

3. Study various specimens of Euglena with the high power. Distinguish the ANTERIOR and POSTERIOR ENDS. Note: (1) the FLAGELLUM which is attached in a depression (GULLET) at the anterior end (careful focusing will be necessary); (2) the red pigment spot (STIGMA); (3) the CONTRACTILE VACUOLES and RESERVOIR; (4) the NUCLEUS.

4. The green color of Euglena is due to CHLOROPHYLL. It is present in a number of oval discs (CHLOROPLASTIDS) which are suspended in the protoplasm. Other larger bodies (PYRENOIDS) can generally be noted, which retain the food material after it has been manufactured.

5. Make a drawing about 3 inches long showing all the observed structures.

6. Occasionally, inactive individuals are found which have become almost spherical in shape and which are surrounded by a rather thick CYST wall. Such specimens are ENCYSTED. They may undergo division during encystment. Study any encysted specimens present in your preparation and make drawings to show the structure as observed.

PARAMECIUM

1. Mount a drop of water containing Paramecia, together with a little powdered carmine, and examine with the low power. The animals will be seen as light-colored, rapidly-moving bodies which rotate on their long axis as they swim. With the naked eye, the Paramecia are just barely visible as tiny white specks.

2. Select a quiet animal under the low power and then study with the high power.[1] Distinguish the ANTERIOR and POSTERIOR ends. Note: (1) the clear outer ECTOPLASM with PELLICLE; (2) the granular, inner ENDOPLASM; (3) the fine, vibratile CILIA which cover the entire body; (4) the depression (PERISTOME) which begins at the anterior end and extends obliquely backward to beyond the middle of the body; (5) the MOUTH, located near the posterior end of the peristome; (6) the funnel-like depression (GULLET) which leads from the mouth down into the endoplasm; (7) the position and rhythmic appearance and disappearance of the two CONTRACTILE VACUOLES with their RADIATING CANALS. Focus carefully on the edge of the body and note (8) the layer of tiny oval bodies (TRICHOCYSTS) lying in the ectoplasm just beneath the outer surface.

3. Observe that the current caused by the ciliary action sweeps the carmine particles, which were placed in the drop of water, down the peristome through the mouth opening and into the gullet, at the lower end of which they collect into GASTRIC VACUOLES. Note the numerous gastric vacuoles containing the carmine particles in the endoplasm.

4. Make a drawing about 3 inches long showing the structures observed.

5. Remove the cover glass of the preparation you have been studying and add a drop or two of acetic carmine. This will kill the animals and also stain the nuclear apparatus (MACRONUCLEUS and MICRONUCLEUS). Study with the high power and add the details of nuclear structure to your drawing in paragraph 4.

6. Place a drop of water containing Paramecia on a clean slide and kill the animals by adding a drop or two of iodine solution. Note what happens to the cilia and trichocysts. Make a drawing of a small portion of the ectoplasm showing some of the trichocysts with the threads protruded.

7. Make a fresh preparation of the Paramecia and draw any animals you see which may be in a state of DIVISION or of CONJUGATION.

[1] It will probably be necessary to remove the cover glass and add a drop or two of quince seed jelly to the preparation in order to quiet the animals.

VORTICELLA

1. Mount a drop of water containing Vorticellae, together with a little powdered carmine, and examine with the low power. Make a drawing of a small group of the animals attached to a piece of debris.

2. Study the preparation with the high power and note that the general shape of the organism is that of an inverted bell, usually attached by means of a long contractile STALK. Note the outer PELLICLE, the ECTOPLASM, and the ENDOPLASM. Determine how and where the particles of carmine are taken into the body and identify the gastric vacuoles with the carmine particles.

3. Identify the following structures: (1) the PERISTOME, or rounded rim, at the large end of the bell; (2) the DISC, or elevated, plate-like area, included within the peristome and filling the large end of the bell; (3) the VESTIBULE, or depression, between the disc and the peristome; (4) the MOUTH, opening into (5) the GULLET which is a slender tube leading from the vestibule into the endoplasm of the body; and (6) the CONTRACTILE VACUOLE. Determine what parts of the body bear cilia. Study the contractions of the stalk.

4. Make a drawing about 2 inches long showing the general structure of the organism and as many as possible of the details mentioned above.

5. Add a little acetic carmine to your preparation, which will kill and stain the animals, and then note: (1) the long, U-shaped MACRONUCLEUS; (2) the small, round MICRONUCLEUS; (3) the STALK consisting of a SHEATH continuous with the pellicle of the bell, and surrounding the central contractile filament (MYONEMES). Add these structures to your previous drawing.

BACTERIA

1. Mount a drop of stagnant water which contains decaying organic material. Study the preparation carefully with the high power and note the various types of Bacteria which are there present. The straight, rod-like forms are BACILLI; the bent, rod-like forms are SPIRILLA; the extremely small, spherical forms are COCCI, and the very long filamentous forms filled with tiny, yellow sulfur granules are BEGGIATOA. Note the movement which each kind of Bacteria exhibits. Compare with Brownian movement (p. 271). Make a drawing of the field under observation, showing all kinds of Bacteria which you have found there.

2. Mount a little of the substance secured from between your teeth. Study the preparation under the high power. Identify and draw the various forms of Bacteria which you find in it.

3. Mount a drop of water in which a piece of meat has been decomposing. Study the preparation under high power. Identify and draw the various forms of Bacteria which you find in it.

4. Examine, under the high power, permanent preparations of various kinds of Bacteria and draw a few cells of each kind.

YEAST

1. Examine a flask of water in which some compressed Yeast and sugar have been placed. Note the physical characters of the fluid, including the smell, color, and taste, and also the minute bubbles of carbon dioxide which are continually rising to the surface.

2. Mount a drop of the scum from the liquid and examine with both the low and the high power. Note the oval YEAST CELLS with the much larger STARCH GRAINS interspersed among them. Under the high power, make a drawing of the field under observation.

3. Make a series of drawings to show the asexual reproduction of the Yeast cells by BUDDING. Draw a large COLONY of the Yeast cells. How many cells are there in a Yeast plant?

4. Treat the preparation with a very small amount of iodin solution. The starch grains are stained a deep blue and the Yeast cells are stained brown.

5. Make a large drawing to show the STRUCTURE of a Yeast cell, noting CELL WALL, CYTOPLASM, generally with numerous tiny granules, and the large, central VACUOLE. The nuclear material in the Yeast cells cannot be distinguished except by special methods of staining.

BREAD MOLD

1. Examine with the dissecting microscope, the white, filamentous fungus growth on a piece of moldy bread and note its general appearance.

2. Place a very small piece of bread, which bears the Mold, in a drop of water on a slide and tease it apart with dissecting needles. Then mount and examine with the low power of the compound microscope. Note that the Mold is composed of a network of fine filaments, or HYPHAE. The hyphae taken together constitute the MYCELIUM.

3. Study the mycelium and identify the following forms of hyphae: (1) the relatively thick STOLONIFEROUS HYPHAE which ramify through the substance of the bread; (2) the groups of short ROOT-LIKE HYPHAE; (3) the ERECT HYPHAE (SPORANGIOPHORES), each of which bears at its apex a SPORANGIUM containing great numbers of tiny, brown SPORES. Draw a portion of the plant which shows all these parts.

4. Make four drawings of SPORANGIA in different stages of development, ending with the fully developed stage in which the spores are being discharged.

5. Examine the discharged spores with the high power and draw a few of them to show their general structure.

VOLVOX

1. Place a drop of water containing Volvox on a slide. Examine, *without cover glass*, under the low power. Each Volvox colony will be seen as a more or less transparent, hollow sphere. Note that each colony is composed of a large number of tiny, greenish bodies (SOMATIC CELLS) which are embedded in a transparent, gelatinous material. In many cases a number of smaller spheres are enclosed within the walls of the parent colony. These are the DAUGHTER COLONIES, and they have arisen asexually by repeated divisions of specialized reproductive cells (PARTHENOGONIDIA) which develop without fertilization. Make an enlarged drawing of a Volvox colony to show the structure as observed.

2. Carefully place a cover glass on the preparation and examine with the high power. Focus on the wall of a colony at the equator, so as to get a profile view of the cells in this region. Make a careful study of a number of the somatic cells and note that the cell body of each consists of an irregular-shaped, colored bit of cytoplasm. Branching out from each cell body are very fine cytoplasmic strands which run through the intercellular material and connect with other cell bodies so that there is a protoplasmic continuity among the cells of the colony. Each cell also possesses two flagella which project to the exterior. Draw a portion of the wall of the colony giving a profile view of the cells as outlined above.

3. Focus on one of the asexual daughter colonies. Note the comparatively small amount of intercellular material between the cells. Draw a portion of the wall of the colony.

4. If material is available, study a Volvox colony in which sexual cells are present. In such a colony note (1) a SPERMARY, which consists of a large number of SPERM CELLS, or MALE GAMETES, grouped together to form a rather flat plate, and (2) an OVARY of about the same size as the spermary, but which contains only a single EGG CELL, or FEMALE GAMETE. Both the spermaries and ovaries are embedded in the wall of the colony and arise from specialized cells. Draw to show the structure as observed.

SPIROGYRA

1. Mount a few filaments of Spirogyra and examine with the low and the high power. Draw a portion of one of the filaments to show its division into cells.

2. Study under the high power. Note the cell walls and the connection between adjacent cells. Note also in each cell the long, green, spiral CHLOROPLASTIDS. Count them and make out their arrangement.

3. Stain the preparation with a *small* drop of iodin solution. Note the changes of color in the rounded bodies embedded in the chloroplastids. These are the reserve food bodies (PYRENOIDS), and their blue color, after the treatment with iodin, indicates the presence of starch.

4. Examine carefully the cell wall and note the thin layer of CYTOPLASM, which lines it internally, and the large VACUOLE, filled with cell sap, which occupies the greater part of the cell. Focus carefully near the center of the cell and find the NUCLEUS, surrounded by a thin layer of the cytoplasm and suspended by delicate strands of cytoplasm which run out to the layer of cytoplasm lining the cell wall.

5. Make a drawing about two inches in length of a single cell showing the detailed structure and the connection with adjacent cells.

6. ASEXUAL REPRODUCTION: Examine a number of filaments carefully for evidence of recent multiplication by transverse division of some of the cells. Draw.

7. SEXUAL REPRODUCTION: Examine a permanent preparation which shows the filaments in process of CONJUGATION. Study with the high power and draw as many stages of conjugation as can be found, including the fully formed ZYGOTES.

MOSS

1. In the Moss the sexual generation (GAMETOPHYTE) consists of a short, upright stem which bears leaves, arranged in spirals, and fine, filamentous RHIZOIDS which function as roots.

2. The asexual generation (SPOROPHYTE) is an atypical, dependent structure which develops from a fertilized egg, near the tip of the gametophyte to which it remains attached. The sporophyte consists of a FOOT which is attached to the gametophyte; (2) a long, thin STALK, and (3) a highly developed SPORE CAPSULE filled with spores.

3. Examine, with the dissecting microscope, a specimen of the Moss plant which shows the gametophyte with the sporophyte attached to it. Identify the structures mentioned above and make a drawing to show them.

4. Open the capsule of the sporophyte and note that it contains the tiny, brown SPORES. Mount a few of these, study their structure under the high power, and draw a few of them.

5. Study, with the low power, a prepared slide [1] on which has been mounted the tip of a gametophyte to show the sexual organs situated there. Note: (1) the larger, club-shaped male organs (ANTHERIDIA) which contain great numbers of SPERM CELLS; (2) the slender, female organs (ARCHEGONIA) with enlarged basal portions, or VENTERS, each of which contains a single EGG CELL; (3) the numerous rod-like structures (STERILE HAIRS) which are found interspersed among the reproductive organs. Make a drawing to show the structures observed.

[1] If a prepared slide is not available, a satisfactory fresh preparation can be made by carefully dissecting the tip of the gametophyte stem under a dissecting microscope.

COMMON FERN

1. In this plant the sexual generation (GAMETOPHYTE) consists of a very small, green, independent, leaf-like structure known as a PROTHALLUS. The asexual generation (SPOROPHYTE) is the large, leafy fern plant which shows a differentiation into ROOT, STEM, and LEAVES.

A. Asexual

2. The stem (RHIZOME) of the Fern sporophyte grows underground. It bears the leaves, which grow upward and the roots which grow downward. The portion of the plant above ground consists of the leaf stalks (PETIOLES) and the body of the leaves (LAMINAE). Each leaf is subdivided into a number of lobes (PINNAE), and these are further subdivided, in some species, into leaflets (PINNULES).

3. Examine the leaves and note that they are of two kinds: (1) sterile leaves (FOLIAGE) and (2) fertile leaves (SPOROPHYLLS) on the under surface of which the spores are developed in the brown-colored bodies (SORI). The sori are partly covered by flap-like outgrowths (INDUSIA) of the epidermal cells on the surface of the leaf.

4. Make (1) a drawing of the upper surface of a foliage pinna indicating the VENATION and (2) of the under surface of a fertile pinna to show the sori.

5. Scrape off a few of the sori and place them in a drop of water on a slide. Tease them apart with dissecting needles, cover, and examine under the low power. Note that they contain numerous spore cases (SPORANGIA), which are filled with the minute brown SPORES. Note also the manner in which the sporangia open to discharge the spores by the action of the ANNULUS. Make a drawing to show the structures observed.

B. Sexual

6. Study a permanent mount of a prothallus, first, with a dissecting microscope and then with the low power of a compound microscope. Note: (1) the filamentous RHIZOIDS by which it is attached to the soil; (2) the male sexual organs (ANTHERIDIA) which occur near the base of the prothallus among the rhizoids; (3) the female sexual organs (ARCHEGONIA) which occur near the notch at one end of the prothallus. Make a drawing of the under surface showing the structures observed.

7. Examine material which shows a young sporophyte developing from the archegonium of the prothallus.

SEED AND SEEDLING

A. Bean

1. Examine a Bean seed which has been soaked in water overnight. Note the scar (HILUM), which marks the place of attachment to the parent plant, and, at one end of the hilum, a tiny opening, the MICROPYLE. Draw.

2. Remove the outer SEED COAT, thus exposing the two thick white seed leaves, or COTYLEDONS, which are attached to, and form a part of, the small, rod-like embryo proper. One end of the embryo (RADICLE) is somewhat pointed, and this becomes the root. The other end, which lies between the cotyledons, is the primary bud (PLUMULE) of the shoot and bears two tiny leaves. The portion of the embryo below its attachment to the cotyledons is the HYPOCOTYL. Draw to show the structures observed.

3. Examine and draw a bean seed, which has begun to germinate, and a series of seedlings from one to three weeks old. Note particularly in each stage: (1) the change in shape, color, and position of the cotyledons; (2) the development of the shoot, consisting of the stem, with NODES and INTERNODES, and the leaves, and (3) the development of the PRIMARY ROOT and its branches, the SECONDARY ROOTS.

B. Corn

4. Examine a Corn seed which has been soaked in water overnight. Note that the embryonic area is to be seen as a white portion on one side, near the small end of the seed. With a sharp scalpel cut the seed in half, in a longitudinal plane, passing through the center of the embryonic area. Study the cut surface of one of the halves under the dissecting microscope. Note: (1) that the greater portion of the seed is filled with the food material (ENDOSPERM) which shows a differentiation into the hard endosperm and the soft endosperm; (2) that the small embryo, which lies to one side and at the small end of the seed, is in contact with the soft endosperm by the single atypical cotyledon, or SCUTELLUM, and (3) that the main growing region of the embryo, as in the Bean, consists of the hypocotyl with the plumule at the upper end and the radicle pointing down. Draw to show the structures observed.

5. Examine and draw a germinating Corn seed and a series of seedlings as in paragraph 3.

ROOT

1. Place a small Radish seedling on a slide and examine it with the dissecting microscope. Note particularly the root with the definite area of root hairs. Draw the entire seedling.

2. With a sharp scalpel, carefully cut off the tip of the root at a point just above the root hair zone and make a temporary mount of it. Be sure that sufficient water is placed under the cover glass so that the piece of root is entirely surrounded. Examine the preparation under the low power. Note the ROOT HAIRS, GROWING POINT, and ROOT CAP. Make a drawing to show these structures.

3. Stain the preparation you have been studying with a drop of iodin. This treatment should differentiate the cytoplasm and nuclei of the root hair cells. When observed, add them to your drawing in paragraph 2.

4. Secure a transverse section through the root hair zone of a young Corn root, mount and examine the preparation under the low power. Note: (1) in the center of the section the compact, circular central cylinder (STELE); (2) lying next to this, a second cylinder (CORTEX) composed of several layers of larger cells, and (3) the outer cylinder (EPIDERMIS) composed of a single layer of elongated cells, many of which show a definite projection of the outer wall to form the long, filamentous root hairs. Make a drawing to show the structure as observed.

STEM

1. Examine, with the low and with the high power, a permanently mounted transverse section of a dicotyledonous stem, such as Aristolochia. Note that it is composed of three cylinders, namely:

(1) An outer cylinder (EPIDERMIS) consisting of a single layer of rectangular cells with thickened outer edges.

(2) A middle cylinder (CORTEX) which is divided into (*a*) a strengthening layer (COLLENCHYMA) next to the epidermis and (*b*) the chlorophyll-bearing layer (CHLORENCHYMA). The cells of the innermost layer of the chlorenchyma are larger, contain starch, and comprise the STARCH SHEATH.

(3) The highly differentiated central cylinder (STELE) consists on the outside of (*a*) several layers of cells with thickened walls, which form a definite ring of strengthening tissue (SCLERENCHYMA) just interior to the starch sheath of the cortex; (*b*) the VASCULAR BUNDLES, composed of the inner XYLEM portion with large ducts, and the outer PHLOEM portion. The xylem and phloem are separated by the actively-growing meristem cells of the CAMBIUM which, in the dicotyledonous stem, forms a ring of tissue around the stem and thus connects the vascular bundles, and, finally, (*c*) the PITH, comprising undifferentiated cells which occupy a considerable area in the center of the stem.

Draw the entire section in outline, and then carefully fill in a quadrant to show the structure as observed.

2. Examine a piece of the young stem of an Oak which has been sawed so as to show transverse, longitudinal, and tangential sections. Identify and make a drawing to show the following structures: (1) the BARK; (2) the CAMBIUM RING; (3) RINGS OF ANNUAL GROWTH; (4) MEDULLARY RAYS, and (5) PITH.

BUD

1. Examine, with the low power, a prepared,[1] median, longitudinal section of the unprotected bud of Elodea. Note that it consists of (1) the central stalk, or rudimentary stem, and, branching from it, (2) the rudimentary leaves in various stages of development. The diameter of the rudimentary stem is larger in the older portions of the bud and it gradually decreases until it terminates in (3) the GROWING POINT which is composed of the rapidly-dividing, embryonic cells (MERISTEM TISSUE).

2. Note that the leaves develop in a regular order in the bud, the youngest leaves being nearest the growing point. In the early stage they consist of only a few cells and form small mounds on the surface of the stem. The older leaves overarch the growing point and form a protection for it. Make a drawing to show all structures observed.

3. Examine, with the naked eye and also with the dissecting microscope, the protected bud of the Lilac. It consists of the same parts as the naked bud of Elodea, but, for protection during the winter, the outer leaves of the bud (SCALE LEAVES) are differentiated from the inner leaves (FOLIAGE LEAVES). Make a slightly enlarged drawing of the entire bud to show the external structure.

4. Carefully remove one by one the leaves of the bud, both scale and foliage, and arrange them in regular order. Note the transition from the scale leaf to foliage leaf. Draw a number of the leaves to show the transition between the two types as observed.

5. Take another Lilac bud and cut it transversely into halves. Examine the cut surface of one of the halves with the dissecting microscope and note the arrangement (VERNATION) of the young leaves in the bud. Draw to show the structure observed.

[1] If a prepared slide is not available, a satisfactory fresh preparation can be made by carefully dissecting a bud under a dissecting microscope.

LEAF

1. Examine a leaf of a MONOCOTYLEDONOUS plant (*e.g.*, Corn). Note the longitudinal parallel VEINS. Make a drawing of the upper surface.

2. Examine a leaf of a DICOTYLEDONOUS plant (*e.g.*, Rose). Note: (1) the leaf stalk (PETIOLE); (2) the leaf blade (LAMINA) with (3) the prominent MIDRIB, and (4) the net-like arrangement of the smaller VEINS. Make a drawing of the upper surface.

3. With the point of a scalpel remove a small portion of the outer covering (EPIDERMIS) from the *under* surface of a leaf. Mount and study with the low power. Note: (1) the epidermal cells and, among them, (2) the openings into the leaf (STOMATA) through which the interchange of gases takes place. Each stoma is enclosed by (3) two specialized epidermal cells (GUARD CELLS). Make a drawing of the epidermis to show the structures observed.

4. Examine, with the low power, a prepared transverse section of a Rose leaf. Select a portion of the leaf to one side of the midrib and study with high power. Note: (1) the upper layer of large, irregularly-shaped cells (UPPER EPIDERMIS), below which can be seen two rows of (2) smaller cells (PALISADE CELLS) oriented with their long axes at right angles to the upper epidermis. Below these is (3) an area in which the cells are not so definitely arranged (SPONGY CHLORENCHYMA) and in which (4) intercellular spaces (LACUNAE) are present. The lacunae open to the exterior through the stomata. The palisade cells and the spongy chlorenchyma together comprise (5) the CHLORENCHYMA. The cells of the chlorenchyma contain (6) the chlorophyll-bearing bodies (CHLOROPLASTIDS). (7) The VASCULAR TISSUE of the veins appears, in transverse section, as more or less circular groups of irregular, lightly-stained cells embedded in the spongy CHLORENCHYMA. (8) The under surface of the leaf is covered with a layer of epidermal cells (LOWER EPIDERMIS) similar to the upper surface, but more stomata are present. Make a drawing of the section to show the structures observed.

FLOWER

1. Examine the flower provided and note that it is composed of WHORLS of modified leaves attached to a slightly enlarged portion (RECEPTACLE) of the stalk as follows: (1) The outermost whorl (CALYX) consists of a number of leaf-like structures (SEPALS). The sepals form the outer covering of a flower bud. They are frequently green in color, and the basal portions are often united to form a tube. (2) The next whorl (COROLLA) consists of PETALS. These may be of various colors and, in some flowers, are united to form a tube. The calyx and corolla together constitute the PERIANTH, and are the ACCESSORY parts of the flower as distinguished from the ESSENTIAL parts which they enclose. These latter consist of (3) a whorl of STAMENS and (4) the central PISTIL. Make an enlarged drawing of a longitudinal section of the flower to show the relations of the parts as observed.

2. Carefully detach one of the stamens, place it on a slide, and study with the dissecting microscope. Note that it consists of (1) a stalk (FILAMENT) and (2) head (ANTHER). The latter contains (3) the tiny POLLEN GRAINS, or MICROSPORES, enclosed in pollen sacs, or microsporangia. Make a drawing to show the structure as observed.

3. Place some of the pollen grains on a slide and study them with the compound microscope. Draw.

4. Mount some pollen grains which have germinated and formed the pollen tube (MALE GAMETOPHYTE). Study under the high power and make a drawing.

5. Remove the calyx, corolla, and stamens from your specimen. Examine the pistil with the dissecting microscope. Note that it consists of (1) an enlarged basal portion (OVULE CASE) from which projects (2) a stalk (STYLE). The style terminates in (3) an enlarged portion (STIGMA) which secretes a sticky substance to which the pollen may adhere. Draw to show the structures observed.

6. Cut the ovule case transversely in half. Examine the cut surface of one of the halves with the dissecting microscope. Make a drawing to show the cavities containing the immature seeds (DEVELOPED OVULES) and the attachment of the latter to the PLACENTA.

FRUIT

1. Examine a small partially developed Apple. Identify the stem end and the flower end. Note that the fruity portion of the Apple, which is a typical example of the POME type of fruits, is developing from the enlarged receptacle at the tip of the stem.

2. With the scalpel, cut the specimen in half transversely. Examine the flower end, and also the cut surfaces under the dissecting microscope. Identify, and ascertain the number of sepals, petals, stamens, carpels in the compound pistil, and developing seeds. Make a drawing of the flower end of the Apple to show the general structure.

3. Cut a mature Apple exactly in half longitudinally. Examine a cut surface. Note that the flesh is divided into a large, outer fruity portion, all of which develops from the walls of the receptacle, and the small, inner portion(CORE), containing the seeds, which develops from the walls of the ovule case. Make a drawing of a cut surface to show the general relations as observed.

4. Take out one or two of the seeds, noting their attachment at one end to the placenta. Remove the hard seed coat, thus exposing the embryo which is essentially similar in structure to that previously studied in the Bean seed.

HYDRA

1. Examine, with the dissecting microscope, a living Hydra in a watch glass containing water. Observe the animal both when expanded and when contracted. Touch the expanded animal with a dissecting needle and observe the rapidity of contraction.

2. Examine the animal in the watch glass as before, with the low power of the compound microscope. Note (1) the BODY, which resembles an elastic tube, and is attached at one end by (2) the FOOT. (3) At the opposite end (HYPOSTOME) of the body there is (4) a central opening (MOUTH) which is surrounded by (5) a circlet of TENTACLES. Note the number of tentacles your specimen possesses and compare with others at your table.

3. Focus on the cellular body wall and note that it is composed of (1) the outer layer (ECTODERM) and (2) an inner layer (ENDODERM) which surrounds (3) a large central cavity (ENTERIC CAVITY) into which the mouth opens. Focus on one of the tentacles and note that it is also composed of ectoderm and endoderm, and that the enteric cavity continues throughout its length. Note the batteries of stinging cells (NEMATOCYSTS) embedded in the ectoderm of the tentacles.

4. Hydra commonly reproduces asexually by budding. Examine your specimen and see if any BUDS are present. At certain seasons of the year it also reproduces sexually. At such times the male gonads (TESTES), which produce the sperm, develop as swellings in the body wall just below the tentacles and the female gonads (OVARIES), which produce the eggs, develop nearer the foot.

5. Make (1) a detailed drawing of an expanded animal, showing all the parts observed above, and (2) an outline drawing of a contracted animal.

6. Examine, with the low and with the high power, a prepared transverse section through the body of Hydra. Note: (1) the outer layer of ectoderm and (2) the inner layer of endoderm, both of which are composed of a great number of cells and are separated from each other by (3) a thin, non-cellular layer (MESOGLOEA). These layers surround (4) the central enteric cavity. Draw the section as observed.

OBELIA

ASEXUAL STAGE

1. Examine, with the dissecting microscope, a specimen of Obelia which has been stained and mounted. Note the general form of the colony.

2. Study the preparation with the low power of the compound microscope. Note: (1) the upright stalk (HYDROCAULUS) with the side branches, each of which bears either (2) a hydra-like nutritive zooid (HYDRANTH) or (3) a club-shaped reproductive zooid (GONANGIUM). The stalk is composed of (4) an inner, deeply staining portion (COENOSARC), which is a continuation of the same material in each zooid, and (5) an outer, transparent exoskeletal sheath (PERISARC) which encloses all parts of the colony. Note that the perisarc expands into (6) a cup-shaped structure (HYDROTHECA) surrounding each hydranth and into (7) a longer, urn-shaped structure (GONOTHECA) which encloses each gonangium. Observe the constrictions in the perisarc below each zooid.

3. Study a hydranth and note: (1) the body wall composed of an outer layer of ectoderm and an inner layer of endoderm, both of which are continuous with the coenosarc in the stalk; (2) the central ENTERIC CAVITY, and (3) the tentacles which surround (4) the mouth.

4. Study a gonangium and note that the club-shaped stalk (BLASTOSTYLE) which, as in a hydranth, is continuous with the coenosarc, bears numerous MEDUSA BUDS. Note the opening at the tip of the gonotheca through which the mature medusa buds escape as free-living animals.

5. Make a large drawing of an Obelia colony showing the structures observed.

GONIONEMUS

1. Examine with the naked eye, in a watch glass containing water, a preserved jelly fish of the hydrozoan type (*e.g.*, Gonionemus). Note the gelatinous consistency of the body and the umbrella, or bell, shape. The upper convex surface is called the ABORAL, or EXUMBRELLA, and the lower concave surface is called the ORAL, or SUBUMBRELLA.

2. Study the oral surface of the specimen with a dissecting microscope. Note: (1) the TENTACLES attached near the periphery, each with an adhesive pad near its tip; (2) the perforated, circular diaphragm (VELUM) attached below the tentacles; (3) the central structure (MANUBRIUM) suspended from the top of the bell and made up of (4) the wide-lipped MOUTH, which opens into (5) the ENTERIC CAVITY.

3. Radiating from the base of the manubrium are (6) the four RADIAL CANALS bearing (7) the reproductive glands (GONADS). The radial canals lead to the periphery of the disc where they connect with (8) the CIRCULAR CANAL, which encircles the periphery near where the tentacles are attached. Note also (9) the SENSE ORGANS which are located about the margin of the bell at the base of each tentacle and also between the bases of some of the tentacles.

4. Make (1) a drawing of the specimen from the oral surface, and (2) from the side, to show the structures observed.

EXTERNAL ANATOMY OF THE EARTHWORM

1. Examine an Earthworm and note the long, tubular body made up of a large number of segments (METAMERES). Identify the anterior, posterior, dorsal, and ventral regions of the body. Count the segments of your specimen and compare the number with others at your table. Note: (1) the MOUTH, which is situated at the anterior end of the body below the projecting lobe (PROSTOMIUM); (2) the ANUS situated at the posterior end of the body, where it can be seen as a vertical slit in the last segment, and (3) the swollen region (CLITELLUM) lying in the region between segments 28 and 35.

2. With one hand take hold of the anterior end of the Earthworm and draw the body through the fingers of your other hand. The rough feeling is due to the presence of bristles (SETAE) which project through the body wall. Ascertain the arrangement of the setae and the number present on each segment.

3. Examine your specimen with the dissecting microscope and find the following openings: (1) openings of the SPERM DUCTS in the swellings on the ventral surface of segment 15; (2) openings of the OVIDUCTS just lateral to the inner double row of setae in segment 14; (3) openings of the SEMINAL RECEPTACLES in the grooves between segments 9 and 10, and 10 and 11, on a line with the outermost row of setae; (4) openings of the NEPHRIDIA just lateral and anterior to the setae of the inner row on either side of each segment; (5) openings of the DORSAL PORES on the anterior end of each segment in the median dorsal line.

4. Make (1) a drawing, twice natural size, of the anterior forty segments of the body from the ventral surface, and (2) a drawing, at the same magnification, of the posterior ten segments of the body from the dorsal surface to show the structure as observed.

INTERNAL ANATOMY OF THE EARTHWORM (1)

1. Place a preserved Earthworm, dorsal surface up, in a dissecting pan and fasten it with one pin through the prostomium at the anterior end of the body, and another through the posterior end of the body. With fine scissors cut very carefully through the body wall in the median dorsal line, beginning just posterior to the clitellum. Extend the cut to the anterior end of the animal, being careful to cut only through the body wall so as not to injure the intestine just below. Beginning at the posterior end of the cut, spread the cut edges by carefully cutting away the segmental partitions (SEPTA), which attach the body wall to the alimentary canal. Fasten the cut edges of the body wall to the parafine with pins. Slant the pins so as not to interfere with your study of the specimen.

2. Examine the specimen and note: (1) the rather thick BODY WALL consisting for the most part of muscular tissue; (2) the body cavity (COELOM) which is divided into a linear series of chambers by the septa; (3) the ALIMENTARY CANAL running the length of the body through the coelom as a straight tube, and (4) the DORSAL BLOOD VESSEL, generally full of coagulated blood, which runs along the top of the alimentary canal. It gives off (*a*) small segmental branches which run to the body wall and alimentary canal, and (*b*) at the anterior end, in segments 7 to 11, five pairs of contractile, thick-walled vessels (AORTIC LOOPS). The latter pass around the digestive tract and unite below with the VENTRAL BLOOD VESSEL.

3. Examine the alimentary canal and note that it consists of the following parts: (1) the MOUTH which opens just below the overhanging prostomium; (2) the thick, muscular PHARYNX extending back to segment 6 and attached to body wall by many fine muscles; (3) the thin-walled OESOPHAGUS, largely obscured by (4) the overlying REPRODUCTIVE ORGANS extending between segments 7 and 14; (5) the CROP at about segment 14; (6) the thick-walled, muscular GIZZARD at about segment 18; (7) the INTESTINE extending from the gizzard to (8) the ANUS at the extreme posterior end of the body.

4. Make a drawing, twice natural size, to show these structures as observed, being careful that each organ is drawn correctly with reference to the segments.

INTERNAL ANATOMY OF THE EARTHWORM (2)

1. Fasten the specimen, which you worked on the last time, in a dissecting pan as before. Make a transverse cut through the alimentary canal a few segments posterior to the gizzard. Gently move the cut ends slightly to one side and find the white-colored nerve cord lying directly below in the median line. Carefully remove the portion of the alimentary canal, lying anterior to the cut just made, as far as the pharynx, but in so doing be sure first to cut all the septa which hold it, so as not to disturb the underlying nerve cord.

2. Trace the nerve cord to the anterior end of the pharynx, where it divides to form a nerve collar (CIRCUMPHARYNGEAL CONNECTIVES) which encircles the anterior end of the pharynx. Examine the dorsal surface of the nerve collar under the dissecting microscope and note the bilobed swelling (CEREBRAL GANGLION) which constitutes the BRAIN of the animal. If the dissection has been carefully made, nerves can be seen running from the cerebral ganglion to the extreme anterior end of the body.

3. Examine the exposed portion of the nerve cord with the dissecting microscope and note that, in each segment, it expands to form a definite enlargement (GANGLION) from which two pairs of LATERAL NERVES arise. Anterior to the ganglion in each segment, find another smaller pair of nerves. All these nerves can be traced into the muscles of the body wall.

4. Continue your examination with the dissecting microscope and note, in each segment, lying close to the body wall on each side of the nerve cord, a tiny, greatly-coiled, tubular structure (NEPHRIDIUM) which is an important excretory organ. Note also the glistening, white longitudinal muscle tissue of the body wall.

5. Make an enlarged drawing of the anterior end of the Earthworm to show the structures as observed.

BODY PLAN OF THE EARTHWORM

1. Examine, with the low and high power, a prepared transverse section through the body of an Earthworm. Draw the section in outline, about four inches in diameter, and then fill in a quadrant to show the general structure as follows:

(1) Body Wall, which consists of: (*a*) a very thin, transparent outer membrane (CUTICLE); (*b*) a layer of elongated, epidermal cells (EPIDERMIS); (*c*) a layer of CIRCULAR MUSCLES and (*d*) a thicker layer of LONGITUDINAL MUSCLES, which together comprise most of the body wall, and (*e*) a very thin layer of PERITONEAL EPITHELIUM, lining the coelom.

(2) Alimentary Canal, which appears in a transverse section as a ring of tissue with a dorsal thickening and infolding (TYPHLOSOLE). The wall of the canal consists of (*a*) an outer layer of rounded gland cells (CHLORAGOGUE LAYER) which also fill the cavity of the typhlosole; (*b*) a muscular layer with both circular and longitudinal fibers; (*c*) a vascular layer with many tiny blood vessels, and (*d*) a layer of ciliated, elongated cells (LINING EPITHELIUM) which form the inner lining of the tract and are the essential agents in the digestion and absorption of food. A section through the dorsal and through the ventral blood vessels can be noted, lying above and below the digestive tract respectively.

(3) Nerve Cord, which consists of two distinct structures, the outer envelope, or SHEATH, and the inner nervous portion. The sheath consists of a thin, outer epithelial layer which encloses a thicker muscular layer. Embedded in the muscular layer, dorsally, are the three GIANT FIBERS, which run the length of the cord, and, ventrally, the SUBNEURAL blood vessel. The nervous portion of the cord within the sheath is bilobed and contains nerve cells and fibers. If the section happens to be through the region of a ganglion a pair of the lateral nerves may be seen.

EXTERNAL ANATOMY OF THE CRAYFISH (1)

1. Examine a preserved Crayfish and note that the body, which is entirely covered with a chitinous EXOSKELETON, consists of a rigid anterior portion (CEPHALOTHORAX) and a jointed, flexible, posterior portion (ABDOMEN).

2. The portion of the exoskeleton covering the cephalothorax is known as the CARAPACE. The latter ends anteriorly in a dorsal projection (ROSTRUM). Examine the carapace and note the indentation (CERVICAL GROOVE) in the exoskeleton which marks the division between the HEAD and THORAX. Note: (1) the short ANTENNULES; (2) the long ANTENNAE with the opening of (3) a GREEN GLAND, or kidney, on the basal joint of each; (4) the stalked EYES, and (5) the ventral MOUTH concealed by appendages.

3. The abdomen consists of six similar segments and, at the posterior end, a median structure (TELSON) which is generally regarded as a seventh abdominal segment. Note the anal opening on the ventral surface of the telson. Examine the abdominal segments and note how they are joined together so as to permit movement. Attached to most of the abdominal segments is a pair of typical biramous appendages. In the male, the first two pairs of abdominal appendages are modified and enlarged for the transfer of sperm, while in the female the first pair is greatly reduced. In the female, there is also a cavity (SEMINAL RECEPTACLE) in the mid-ventral line between the fourth and fifth walking legs. Determine the sex of your specimen.

4. Examine the exoskeleton of a detached abdominal segment and note: (1) the dorsal, arched portion (TERGUM); (2) the ventral, calcified bar (STERNUM) with the soft cuticle on each side which permits movement, and (3) the downwardly projecting, lateral portions (PLEURA). Examine the paired, biramous appendages and note: (4) the basal portion (PROTOPODITE) which is attached to the body and bears (5) two jointed branches (EXOPODITE and ENDOPODITE).

5. Make (1) a drawing of the entire animal from the left side and (2) a drawing of a detached abdominal segment from one end.

EXTERNAL ANATOMY OF THE CRAYFISH (2)

1. Carefully cut off a portion of the carapace from the left side of your specimen, thus exposing the BRANCHIAL CHAMBER containing the GILLS. Then lay the animal on its right side under water. Note the feathery character of the gills and their attachment either to the appendages or to membranes present at the base of the appendages. Find the modified, paddle-shaped portion (SCAPHOGNATHITE) of the second maxilla, which lies in the anterior end of the branchial chamber and, by its movements, keeps a current of water bathing the gills.

2. Carefully examine and identify all of the appendages, using your textbooks. Then, beginning at the posterior end of the body, carefully remove all the appendages one by one from the left side of the animal and pin each one in a dissecting pan in its proper order and position. In removing them, be sure to get the whole of each appendage, including the gills when present. The small appendages around the mouth must be handled very carefully with fine forceps. (W. f. 72.)

3. Study and make a drawing of the following appendages: (1) ANTENNA; (2) SECOND MAXILLA; (3) THIRD MAXILLIPED; (4) FIRST and SECOND WALKING LEGS, and (5) THIRD and SIXTH ABDOMINAL. Identify and label the homologous parts in each.

EXTERNAL ANATOMY OF THE HONEY BEE (1)

1. Examine a freshly killed or preserved Honey Bee of the worker type and note that the body is divided into HEAD, THORAX, and ABDOMEN. Study the specimen with the dissecting microscope. On the head note the jointed ANTENNAE which project from the anterior surface; the large compound eyes, and the mouth parts. Observe that the thorax is composed of three segments, each of which bears a pair of jointed legs. The second and third thoracic segments also bear a pair of wings. Observe that the abdomen, is composed of six visible segments. The exoskeleton of each of these segments is made up of the dorsal TERGUM and the ventral STERNUM. At the posterior end of the abdomen is the anus and the opening for the sexual organs. Make an enlarged drawing of the animal from the left side to show the structures observed.

2. Remove the head, place it on a slide, and study the anterior surface under the dissecting microscope. Note: (1) the large, compound eyes, which project from either side of the head; (2) the small, simple eyes (OCELLI) in the center and almost on top of the head; (3) the pair of jointed antennae and just below them on the anterior surface, (4) a median, dome-shaped structure (CLYPEUS) to which is attached (5) the upper lip (LABRUM). As seen from the anterior surface the chief mouth parts consist of (6) a long, median tongue (HYPOPHARYNX); (7) a pair of LABIAL PALPS, one on each side of the tongue; (8) a pair of wider, projecting MAXILLAE, lateral to the palps, and (9) a pair of MANDIBLES, attached one near either end of the labrum. The mandibles are generally closed, in which position they obscure the underlying labrum. Make an enlarged drawing of the head from the anterior surface to show the structures observed.

EXTERNAL ANATOMY OF THE HONEY BEE (2)

1. With fine forceps, carefully remove the left PROTHORACIC LEG, being sure that you secure all the joints. Mount and examine it with the dissecting microscope and also with the low power of the compound microscope. Note that it is composed of five joints which, beginning with the one attached to the body, are designated as follows: (1) COXA; (2) TROCHANTER; (3) FEMUR; (4) TIBIA, and (5) the five-jointed TARSUS. Note: (6) the feathery BRANCHED HAIRS, for gathering pollen, which are present on all the joints except the tarsus; (7) the POLLEN BRUSH and (8) the flattened spine (VELUM) on the tibia; (9) the circular ANTENNA COMB on the first joint (METATARSUS) of the tarsus, which works with the velum on the tibia to form an ANTENNA CLEANER; (10) the EYE BRUSH, also on the first joint of the tarsus, and (11) the FOOT, or terminal portion of the tarsus, which consists of a fleshy pad (PULVILLUS) and a pair of notched claws. Draw to show the structures observed.

2. Remove, mount, and study as before, the left MESOTHORACIC LEG. Observe the SPUR on the tibia, which is used to clean the wings and also to pry out the pollen from the pollen basket on the metathoracic legs. Draw a portion of the leg to show this structure.

3. Remove, mount, and study as before the left METATHORACIC LEG. Note: (1) the concavity (POLLEN BASKET) on the outer surface of the tibia; (2) the row of short, stiff spines (PECTEN) present on the distal end of the tibia; (3) a concave plate (AURICLE) on the first joint of the tarsus; and (4) the POLLEN COMBS, also on the first joint of the tarsus. Draw a portion of the leg to show these structures.

4. With fine forceps remove the last two segments of the abdomen. Place them on a slide under the dissecting microscope and, with a pair of needles, dissect out the sting. Note the following parts: (1) a pair of BARBED DARTS, which with the sheath form a long, rigid, median structure; (2) a pair of fleshy STING FEELERS, one on either side of the darts; and (3) the POISON SAC with attached POISON GLANDS. Draw to show the structures observed.

LIFE HISTORY OF THE MOTH

1. The life history of the Moths and of other Insects with complete metamorphosis, consists of four stages, namely, EGG, LARVA, PUPA, and ADULT.

(1) EGG. The eggs of a Moth are generally laid on, and attached to, leaves which later serve as food for the larvae. Examine, with the dissecting microscope, a preparation of a leaf with the attached eggs and make a drawing.

(2) LARVA. Examine the segmented, wormlike, larval stage (CATERPILLAR) of the Moth and make a drawing to show the following structures: (*a*) the head, which appears as one segment and bears on its anterior surface tiny, simple eyes (OCELLI) and, laterally on each side of the mouth, a pair of jaws (MANDIBLES); (*b*) the THORAX, consisting of three segments, each of which bears a pair of small legs with sharp hooks, and (*c*) the ABDOMEN, consisting of the posterior nine segments, of which five bear unjointed appendages, known as PROP LEGS. Note the openings (SPIRACLES) of the tracheal tubes on each side of certain segments. Draw the animal from the left side to show the structures observed.

(3) PUPA. Examine the silk COCOON which the animal spins and in which it encloses itself at the close of the larval period. Carefully open the cocoon by making a longitudinal incision through it with the tips of the scissors, remove the living pupa, and examine under the dissecting microscope. Identify the HEAD, THORAX, ABDOMEN, ANTENNA CASES, WING CASES, and LEG CASES. Make drawings of (1) the cocoon, and (2) the pupa from the ventral surface.

(4) ADULT. Examine a mounted adult Moth from the dorsal surface. Identify (1) the HEAD, with EYES and ANTENNAE; (2) the THORAX, with FORE and HIND WINGS, and LEGS, and (3) the segmented ABDOMEN. Make a drawing of the dorsal surface, showing all structures possible.

CLAM

1. The shell of a Clam consists of right and left halves (VALVES) which are hinged together along the dorsal surface. Concentric lines of growth are visible on the shell which radiate from a dorsal portion, or UMBO, of the shell where growth started. Draw the external surface of the left valve.

2. Carefully remove the left valve from your specimen, noting the structure of the HINGE and the attachments of the ANTERIOR and the POSTERIOR ADDUCTOR MUSCLES to the interior of the shell. It is necessary to cut both of these muscles before removing the valve. Note that the internal organs are enclosed by a membranous MANTLE which lines both valves of the shell. The space between the two halves of the mantle, in which the organs lie, is known as the MANTLE CAVITY. Turn back the left half of the mantle, cutting a little at each end, and thus expose the structures in the mantle cavity as follows: (1) the large dorsal VISCERAL MASS, from which (2) the ventral muscular FOOT extends; (3) the delicate, striated GILLS, and (4), at the posterior end of the mantle, the dorsal (EXHALENT) and the ventral (INHALENT) SIPHONS.

3. Below the anterior adductor muscle, note the two pairs of PALPS, between which the MOUTH is situated. At the posterior end of the body find the ANUS, which opens into the exhalent siphon, dorsal and slightly posterior to the posterior adductor muscle. Trace the intestine anteriorly from the anus to the HEART which lies in a median dorsal position enclosed in the thin, delicate PERICARDIUM. The heart consists of a single VENTRICLE, through which the intestine passes, and two small, thin-walled AURICLES lying laterally and below and attached to the pericardium. The auricles are easily destroyed in the dissection.

4. Make an enlarged drawing showing the internal structure of the Clam as observed.

EXTERNAL ANATOMY OF THE FROG

1. Examine a Frog and note: (1) the general form of the animal; (2) the division into head and trunk; (3) the fore, and hind, limbs; (4) the opening of the cloaca; (5) the character of the skin (the microscopic structure of the skin is studied in a later exercise, p. 367); and (6) the difference in color between the dorsal and ventral surfaces.

2. Examine the head and note the following structures: (1) the large mouth; (2) the pair of small, external openings, or nostrils (EXTERNAL NARES); (3) the pair of circular ear drums (TYMPANIC MEMBRANES); (4) the protruding eyes; and (5) the tiny nodule (BROW SPOT) in the skin between the eyes. Note how the lower eyelids cover the eyes and how each eye may be drawn into a cavity (ORBIT) in the skull and thus protected from injury.

3. Examine the fore limb and identify the UPPER ARM, FOREARM, and HAND; the latter with WRIST and DIGITS. Examine the HIND LIMB and identify the THIGH, SHANK, and FOOT; the latter with ANKLE, DIGITS, and INTERDIGITAL WEB. Note the difference in length between the two pairs of limbs.

4. Make a drawing of the animal, showing as many of the above characters as possible.

VISCERA OF THE FROG

1. Pin out a freshly chloroformed Frog, with the ventral surface up, in a dissecting tray. With fine forceps lift up the loose skin near the posterior end of the abdomen, and then with scissors make a longitudinal incision, through the skin only, just to one side of the median line and running from the posterior end of the abdomen to the throat. Make a transverse incision in the skin in the pelvic region, and also one just posterior to the fore limbs. Pin out the flap of skin on each side.

2. In the same way make a longitudinal cut through the muscle tissue of the body wall running from the pelvic region to the sternum. Cut through the bony shoulder girdle on each side of the sternum, being *careful* not to injure the underlying heart. Make transverse cuts as before and pin the flap of body wall on each side, over the flap of skin previously pinned out.

3. Examine the large coelom filled with the viscera, which you have now exposed. It is lined with a delicate membrane (PERITONEUM) which is continuous over each of the organs in the body cavity. It also forms folds (MESENTERIES) by which certain organs are suspended and held in place. Identify and study the following structures:

(1) The HEART, at the anterior end of the coelom, enclosed in a delicate, transparent sac (PERICARDIUM). Carefully remove the pericardium. Watch the pulsations of the heart and determine the number per minute. Place your finger tip on the heart while it is beating and note the alternate tension and relaxation. Identify (*a*) the single, thick-walled posterior VENTRICLE; (*b*) the pair of thin-walled anterior AURICLES; and (*c*) the CONUS ARTERIOSUS which leads anteriorly from the ventricle. Lift the heart and locate, underneath, the SINUS VENOSUS which opens into the right auricle. (Continued on page 341.)

(2) The LUNGS, consisting of a pair of thin-walled vascular sacs which communicate to the exterior through the glottis in the mouth. The lungs lie close to the dorsal body wall on each side, near the heart.

(3) The LIVER, consisting of three large, reddish brown lobes which lie in a prominent position lateral and posterior to the heart. Separate the lobes slightly and find the GALL BLADDER, which receives BILE from each of the lobes.

(4) The ALIMENTARY CANAL, consisting of a long tube running from the mouth to the anus. Identify the enlarged STOMACH, which lies to the animal's left just under the tips of the lobes of the liver, and the coiled SMALL INTESTINE, which can be traced posteriorly to the LARGE INTESTINE, or RECTUM. Note the small spherical SPLEEN near by.

(5) The UROGENITAL ORGANS, consisting of the KIDNEYS and either the male gonads (TESTES) or female gonads (OVARIES). These lie close to the dorsal body wall, and can be seen by gently pushing the intestine somewhat to one side.

(6) Arrange the organs to the best advantage, and make a full page drawing to show as many as possible of the observed structures.

BUCCAL CAVITY AND RESPIRATORY ORGANS OF THE FROG

1. Pin the Frog, which you dissected last time, ventral surface up in a dissecting pan. Pull back the lower jaw, cutting a little at each corner, and then pin the edge of the lower jaw to the ventral surface of the body so as to expose fully the cavity of the mouth (BUCCAL CAVITY).

2. Note the upper jaw with (1) a projecting, fleshy upper lip, and bearing (2) numerous very fine MAXILLARY TEETH, which you can feel by rubbing over them with your finger; (3) the two groups of VOMERINE teeth on the dorsal roof of the mouth; (4) the internal nostrils (INTERNAL NARES), one on either side of the vomerine teeth; (5) the openings of the EUSTACHIAN TUBES, posterior to the internal nares.

3. Note the lower jaw with (1) the muscular TONGUE, which is attached anteriorly, and (2) the circular elevation (GLOTTIS) with a median, slit-like opening into the LARYNGO-TRACHEAL CAVITY which leads to the lungs. Leading from the posterior end of the mouth is (3) the OESOPHAGUS, which runs to the stomach. Make a drawing of the entire mouth cavity to show the structures observed.

4. Place the lower jaw in a normal position and then carefully remove the skin from the ventral surface of the body, anterior to the fore limbs. After having carefully cut the attached blood vessels, remove the heart from the body. Locate the pair of lungs which you saw in the last exercise and trace each one to the thin-walled, median laryngo-tracheal cavity which lies just ventral to the glottis, noted above in the study of the buccal cavity. Draw to show the structures observed.

ALIMENTARY CANAL AND ASSOCIATED ORGANS OF THE FROG

1. Secure the specimen previously dissected. Cut off and discard the portion of the lower jaw which lies anterior to the glottis. Next cut through the mucous membrane lining the dorsal part of the mouth cavity just posterior to the openings of the Eustachian tubes. Be careful not to disturb the underlying bony structures of the upper jaw. You have now freed the anterior end of the oesophagus from the body.

2. With your forceps, gently lift up the lower jaw with the attached oesophagus, and then, beginning anteriorly, carefully cut all the mesenteries which attach the alimentary canal to the body. Make a transverse cut through the anterior end of the rectum. Now remove the entire alimentary canal with the attached lungs, liver, and pancreas from the body, taking care not to disturb the underlying urogenital organs. Place the organs which you have just removed in a dissecting pan and pin them out so as to show to the best advantage. It may be necessary to cut some of the mesenteries.

3. Trace the alimentary canal throughout its entire length. Identify and note the structure of the (1) OESOPHAGUS; (2) STOMACH; (3) PYLORIC VALVE; (4) SMALL INTESTINE; (5) PANCREAS with the PANCREATIC DUCT, which joins the BILE DUCT from the gall bladder of the liver before the latter opens into the small intestine; and (6) the RECTUM, which merges into the cloaca.

4. With fine scissors, make a median longitudinal cut through the ventral wall of each lung and continue the cut on each side into the laryngo-tracheal cavity. Pin back the walls of the lungs and larynx, thus exposing the interior of these structures. Note: (1) the structure of the lungs; (2) the pair of small VOCAL CORDS lying on each side of the laryngo-tracheal cavity; and (3) the opening into the mouth cavity through the glottis.

5. Arrange the organs to the best advantage and make a drawing to show as many as possible of the observed structures.

HEART

1. Examine a Pig's heart and note that it is conical in form, with a broad base and a narrow apex. Place it with the apex pointing toward you and note the following external features: (1) the LEFT VENTRICLE, with very thick, muscular walls, continuing to the tip of the apex; (2) the RIGHT VENTRICLE, with thinner walls, lying beside the left ventricle except at the tip, which is entirely formed by the left ventricle; (3) the LEFT AURICLE, and (4) the RIGHT AURICLE, both lying anterior to the ventricles. Both of the auricles are smaller and have much thinner walls than the ventricles, and each is provided with (5) an ear-like flap of tissue (AURICULAR APPENDAGE).

2. Explore the cavity[1] of the left auricle, noting (1) the openings of the PULMONARY VEINS, and (2) the opening into the left ventricle.

3. Explore the cavity of the left ventricle, noting (1) the very heavy, muscular walls; (2) the MITRAL VALVE, guarding the opening from the auricle, the edges of which are attached to (3) elevations (PAPILLARY MUSCLES) of the muscular walls of the ventricle by a number of (4) fine tendinous cords (CHORDAE TENDINEAE). Feel with your finger and find (5) the opening into the AORTA. Study the aorta, noting (6) its heavy, elastic walls; (7) the SEMILUNAR VALVES, and (8) the opening of the CORONARY ARTERY just beyond the valves.

4. Explore the cavity of the right auricle, noting (1) the large openings from the VENAE CAVAE; (2) the small opening of the CORONARY VEIN just posterior to the former; and (3) the opening into the right ventricle.

5. Explore the cavity of the right ventricle, noting (1) the thinness of the walls as compared with the left ventricle; (2) the TRICUSPID VALVE, which shows the same structure as the mitral valve. Find the opening into (3) the PULMONARY ARTERY, which contains (4) semilunar valves, the same as in the aorta.

6. Make a drawing of the heart from the left side, showing as many as possible of the observed structures.

[1] The various chambers of the heart should be opened by cutting through the walls.

UROGENITAL SYSTEM OF THE FROG

1. Pin the specimen, from which you have previously removed the alimentary canal and associated organs, in a dissecting pan, ventral surface up as before. Carefully cut through the bony pelvis in the median line and thus completely expose the CLOACA into which the rectum and the ducts from the urinary and genital organs empty, and on the ventral surface of which the thin-walled, bilobed BLADDER opens.

2. FEMALE FROG. In the spring the right and left ovaries become greatly distended and fill a large portion of the body cavity. Separate the ovaries and push them to either side so that the other organs may be seen to advantage. Note: (1) a pair of reddish, flattened, oval-shaped KIDNEYS, close to the dorsal body wall; (2) a pair of elongated, orange-colored ADRENAL BODIES, one lying on the ventral surface of each kidney; (3) a pair of yellowish FAT BODIES with long finger-like processes; (4) a pair of long, coiled OVIDUCTS which open anteriorly into the body cavity near the base of each lung. Posteriorly, before opening into the cloaca, each of the oviducts enlarges to form (5) a thin-walled UTERUS. Examine the outer margin of the kidneys and find on each (6) a URETER, which can be traced posteriorly to its opening in the cloaca. Note also the blood vessels attached to the kidneys. Make an enlarged drawing to show the structures observed.

3. MALE FROG. Locate and examine the following parts of the male urogenital system: (1) a pair of reddish, flattened, oval-shaped KIDNEYS, close to the dorsal body wall; (2) a pair of white TESTES attached to the kidneys by a number of fine ducts (VASA EFFERENTIA); (3) a pair of elongated, orange-colored ADRENAL BODIES, one lying on the ventral surface of each kidney; (4) a pair of yellowish FAT BODIES with long finger-like processes; (5) in many specimens a pair of small, coiled RUDIMENTARY OVIDUCTS are to be found situated laterally to the kidneys. Examine the outer margins of the kidneys and find (6) the UROGENITAL CANALS, each of which can be traced posteriorly to its opening in the cloaca. Note also the blood vessels attached to the kidneys. Make an enlarged drawing to show the structures observed.

KIDNEY

1. Examine a half of a Pig's kidney. Observe that it is somewhat bean-shaped in outline, with a marked depression (HILUS) on one edge, in which region the ureter arises. Examine the cut surface of your specimen and note that three regions of the kidney can be distinguished as follows: (1) an outer, darker area (CORTEX) containing great numbers of the microscopic, nephridial elements (MALPIGHIAN BODIES); (2) an inner, striated medullary portion (MEDULLA) containing the URINIFEROUS TUBULES, and (3) the PELVIS, which is really the expanded end of the ureter. The uriniferous tubules of the medulla open into the pelvis at the tips of the conical-shaped projections (PYRAMIDS OF MALPIGHI), and the latter are separated from each other by prolongations of the cortex into the pelvis. Make a drawing of the cut surface of the kidney to show the structure as observed.

2. Examine, with the low and the high power, a prepared section of Frog kidney and note the general arrangement, consisting of a comparatively thin area on one side, which contains a number of rounded Malpighian bodies, and a thicker area filled with the URINIFEROUS TUBULES which have been sectioned in various planes. Make a drawing to show the general arrangement.

3. Select a single Malpighian body and focus on it with high power. It consists of (1) a spherical knot of fine blood vessels (GLOMERULUS) containing numerous red blood corpuscles which appear yellow in the preparation, and (2) a definite, surrounding membrane (BOWMAN'S CAPSULE) which is essentially the enlarged end of a uriniferous tubule. Focus on a portion of one of the uriniferous tubules and note the cellular wall and central lumen. Make a drawing of a Malpighian body and of a portion of a uriniferous tubule.

SPINAL NERVES OF THE FROG

1. Pin your specimen in the dissecting pan as before. Remove any of the viscera which may be present in body cavity. Examine the dorsal wall of the body cavity and note the paired SPINAL NERVES which may be seen as small, white cords running laterally from either side of the vertebral column. They arise in the spinal cord and emerge from between the vertebrae through the light colored CALCAREOUS BODIES.

2. Beginning at the anterior end, identify and trace the ten pairs of spinal nerves as follows:

I. A small pair which emerges from between the first and second vertebrae just anterior to the fore limbs, usually giving off a small branch to the second nerve before continuing laterally into the muscles.

II. A large pair which supplies the fore limbs after usually having received branches from the first and third pairs. This union forms the BRACHIAL PLEXUS.

III. A small pair which, after giving off a branch to the second pair, can be traced laterally into the muscles.

IV, V, and VI are small pairs which can be traced into the muscles of the body wall.

VII, VIII, and IX are larger pairs which run almost directly posteriorly and anastomose to form the SCIATIC PLEXUS, from which arises the large SCIATIC nerve. By careful dissection, follow the sciatic nerve from the plexus down through the leg and into the foot, noting the various branches which are given off. Note also a branch of the seventh nerve, which is given off anterior to the sciatic plexus.

X. A small pair, each of which emerges from openings near the anterior end of the urostyle and supplies chiefly the urogenital organs.

3. Make a drawing to show the location and course of the spinal nerves.

CENTRAL NERVOUS SYSTEM OF THE FROG (1)

1. Secure your dissected Frog and carefully remove the skin from all parts of the body. Fasten the specimen, dorsal surface up, in a dissecting pan, and then with a sharp, pointed scalpel, pick off, bit by bit, the bony roof of the skull in the region between the eyes, taking great care not to injure the brain underneath by inserting the scalpel too deeply. Small pieces of the bone may also be snipped off with the tips of the scissors. Continue the area of dissection anteriorly to the nasal region and posteriorly to the end of the skull, thus entirely exposing the dorsal surface of the brain. Note that it is covered by a thin pigmented membrane (DURA MATER) which should be carefully removed with fine forceps.

2. Examine the brain from the dorsal surface and, beginning at the anterior end, note the following parts: (1) the fused OLFACTORY LOBES, from which the OLFACTORY NERVES may be seen extending anteriorly to the nasal region; (2) the pair of CEREBRAL HEMISPHERES which merge anteriorly into the olfactory lobes; (3) an unpaired portion (DIENCEPHALON) bearing (4) a small, median structure (PINEAL GLAND); (5) a pair of egg-shaped OPTIC LOBES, back of which is (6) a transverse elevation (CEREBELLUM), and, posterior to the cerebellum, (7) the MEDULLA OBLONGATA, which appears as the enlarged anterior end of the spinal cord and contains (8) a triangular depression, the FOURTH VENTRICLE. The FORE-BRAIN consists of the olfactory lobes, cerebral hemispheres, and diencephalon; the MID-BRAIN, as seen from the dorsal surface, of the optic lobes, and the HIND-BRAIN, of the cerebellum and medulla oblongata.

3. Make a drawing at least twice natural size to show the dorsal surface of the brain *in situ*.

CENTRAL NERVOUS SYSTEM OF THE FROG (2)

1. Continue the dissection of the central nervous system by very carefully removing, with the tips of the scissors, the bony, dorsal arches of all the vertebrae, thus exposing the SPINAL CORD throughout its entire length.

2. The brain and spinal cord must now be removed from the animal. In order to do this it will be necessary to cut the cranial and spinal nerves which run from the central nervous system to the various regions of the body. Begin at the anterior end of the brain and cut the olfactory nerves first. Then carefully raise the anterior end of the brain, note the large optic nerves on the ventral surface anterior to the optic lobes, and cut them. Continue posteriorly in this manner, and when the entire central nervous system is free, remove it and place in a small dish of water for further study.

3. Study the ventral surface of the brain under the dissecting microscope and locate the region of the fore-brain, mid-brain, and hind-brain. Note: (1) the origin of the olfactory nerves; (2) the origin of the optic nerves and the crossing of the fibers of each in the mid-ventral line under the optic lobes, to form (3) the OPTIC CHIASMA; (4) the heart-shaped INFUNDIBULUM which lies underneath the optic chiasma, and (5) the HYPOPHYSIS, or PITUITARY BODY, which lies in a median position posterior to the infundibulum. The latter is frequently detached from the brain when removing it from the brain case.

4. Study the spinal cord and note: (1) the enlargement in the brachial region where the nerve supply of the fore-limbs arises; (2) the enlargement in the pelvic region where the nerve supply of the hind-limbs arises; and (3) the small terminal portion (FILUM TERMINALE).

5. Make a drawing of the ventral surface of the brain and spinal cord at least twice natural size, showing all the structures observed.

BRAIN

1. Examine the dorsal surface of a Sheep's brain. Note the large anterior CEREBRUM, which consists of a right and left CEREBRAL HEMISPHERE. Posterior to the latter is the median, unpaired CEREBELLUM, lying above the MEDULLA, which merges into the SPINAL CORD. The brain is enclosed in three membranes: (1) the DURA MATER, which lines the interior of the skull; (2) the ARACHNOID, which is the membrane you see, and (3) the PIA MATER, which lies below the arachnoid and is very closely applied to the brain tissue. Note that the outer surface of the cerebrum (CEREBRAL CORTEX) is arranged in ridges (GYRI), between which are depressions (SULCI) of varying depths.

2. Examine the ventral surface of your specimen. Note: (1) the CEREBRAL HEMISPHERES; (2) the OLFACTORY LOBES (often destroyed in removing the brain from the skull), from each of which (3) olfactory nerve fibers arise; (4) the OPTIC CHIASMA, from which (5) the OPTIC NERVES arise; (6) the PITUITARY BODY, under and posterior to the optic chiasma, and lying on (7) the thickened, ventral wall (CRURA CEREBRI) of the mid-brain; (8) the prominent, transverse band of fibers (PONS VARIOLII) with (9) a root of the important fifth cranial nerve (TRIGEMINAL) arising just posterior and on each side; (10) the eighth cranial nerves (AUDITORY) which arise close to the ventral edge of the cerebellum just posterior to the fifth cranial nerve.

3. Examine the cut surface of a brain which has been sectioned in a median longitudinal plane. Note the general arrangement with the large cerebral hemisphere which lies anterior and dorsal to the mid-brain. Identify the following structures in addition to those noted above: (1) the CORPUS CALLOSUM, which consists of a fibrous plate connecting the two cerebral hemispheres; (2) the CORPORA QUADRIGEMINA, which lie just anterior to the cerebellum and constitute the dorsal wall of the mid-brain; (3) the small spherical PINEAL GLAND lying in an indentation anterior to the corpora quadrigemina, and (4) the cavity (FOURTH VENTRICLE) in the medulla, lying underneath the cerebellum.

4. Make a drawing of the half-brain from the cut surface, showing as many as possible of the structures which you have found in the preceding paragraphs.

EYE

1. Place a dissecting microscope on its side in front of you and turn the mirror in such a position that you can examine your own eye. Make a drawing, showing (1) the EYELIDS; (2) the white of the eye (SCLEROTIC COAT) which in front forms (3) the transparent CORNEA; (4) the underlying colored portion (IRIS) with (5) a circular, central opening (PUPIL).

2. Examine a Sheep's eye. Note: (1) the shape; (2) the character of the outer, protective covering (SCLEROTIC COAT); (3) the attachment of the muscles; and (4) the optic nerve.

3. Examine an eye which has been cut in half and find the following structures: (1) the SCLEROTIC COAT, a comparatively thick layer of connective tissue, which, in the front of the eye, forms (2) the transparent CORNEA; (3) the CHOROID COAT, a thin, deeply pigmented, vascular layer which, in the front of the eye, forms (4) the colored IRIS, in the center of which is (5) the circular opening (PUPIL); (6) the transparent LENS, which lies just posterior to the iris; and (7) the sensory layer, or RETINA, which is directly continuous with (8) the OPTIC NERVE, running from the posterior part of the eye to the brain.

4. Note the following chambers of the eye: (1) the ANTERIOR CHAMBER, situated between the cornea and iris; (2) the small POSTERIOR CHAMBER, situated between the iris and lens and communicating with the anterior chamber through the pupil; and (3) the large VITREOUS CHAMBER posterior to the lens, in which the retina lies. The vitreous chamber is filled with a transparent, jelly-like material (VITREOUS HUMOR). The two chambers in front contain a more fluid substance (AQUEOUS HUMOR).

5. Make a drawing, about three inches in diameter, showing the structures as observed.

HISTOLOGY OF NERVE TISSUE

1. Examine, with the low and with the high power, a prepared transverse section through the spinal cord of a Frog. Note: (1) the thin, outer covering (DURA MATER); (2) the rather shallow indentation on the dorsal side (DORSAL FISSURE); (3) the deeper indentation on the ventral side (VENTRAL FISSURE); (4) the outer layer (WHITE MATTER) largely composed of nerve fibers, and less compact than (5) the inner material of the cord (GRAY MATTER) which contains (6) a large number of nerve cells, or NEURONS. In the center of the cord is (7) the open canal (CENTRAL CANAL) which runs the entire length of the central nervous system. If the section happens to pass through a spinal nerve, the (8) DORSAL and VENTRAL ROOTS may be seen connected with the gray matter. Make a drawing of the section to show the structures as observed.

2. Using the high power, focus directly on the large, irregularly shaped MOTOR NERVE CELLS in the ventral portion of the gray matter on either side of the cord. Note the large nuclei and the fibrillated cytoplasm. Try to find a nerve cell which has been sectioned so that it shows a long fiber (AXON) running out from it. Draw one of the cells, showing all details of structure as observed.

3. Secure a small piece of a fresh nerve taken from a chloroformed Frog, place it on a slide in a drop or two of normal salt solution, and tear it apart with dissecting needles. Mount and examine under the microscope. Note that the nerve is composed of a number of fine, thread-like fibers, each of which consists of (1) a delicate, external membrane (NEURILEMMA), (2) a thick layer of fatty material (MEDULLARY SHEATH), and (3) the central nerve fiber, or AXON, which, as noted above, is a direct continuation of the cytoplasm of the nerve cells. At intervals along each fiber, there are breaks (NODES OF RANVIER) in the medullary sheath, but the neurilemma and the axon are continuous. Draw to show the structure as observed.

HISTOLOGY OF MUSCLE TISSUE

1. Unstriated Muscle. Examine, with the low and high power, a prepared transverse section of Frog intestine. Note that it is composed of a number of layers as follows: (1) the thin, outer covering (peritoneum); (2) the muscular layers consisting of an outer longitudinal layer and an inner, thicker, circular layer; (3) the connective tissue layer (submucosa), and (4) the epithelial layer (mucosa) which is thrown into folds, and forms the inner lining of the intestine. The mucosa consists of two types of elongated epithelial cells, one the absorptive cells, and the other the secretive cells, or unicellular glands. The latter type may be distinguished by the presence of a large oval vacuole in each. Draw the section in outline and fill in a portion to show the general arrangement.

2. Study the two layers of unstriated muscle tissue under the high power. Note that the tissue of the circular layer consists of closely packed, elongated, spindle-shaped cells. In the longitudinal layer this same type of muscle cell is to be noted, but in this case the cells have been cut transversely so that the true shape of the cell bodies is not seen. Draw a portion of both layers to show the structure as observed.

3. Striated Muscle. Place a small piece of fresh muscle, from the leg of a Frog, in a drop of normal salt solution on a slide. Tear it thoroughly apart with dissecting needles. Add a drop of acetic carmine stain, mount, and examine with the low and the high power. Note that this type of muscle tissue consists of long, striated, cylindrical bundles of fibers bound together by connective tissue (perimysium). Under the high power study the cytoplasm (sarcoplasm) of the muscle fibers and observe the distinct transverse striations and the less distinct longitudinal striations which are present in them. Stained nuclei may also be found embedded in the sarcoplasm. Draw to show the structure as observed.

HISTOLOGY OF CONNECTIVE TISSUES

1. Fibrous Connective Tissue. Examine, with the high power, a prepared, transverse section of Frog skin. Note that: (1) the outer portion (epidermis) of the skin is made up of several layers of stratified epithelial cells; (2) the inner portion (dermis) of the skin is divided into a comparatively loose layer of connective tissue (stratum spongiosum) which lies next to the epithelial cells and consists of connective tissue fibers, in which are embedded numerous glands, blood vessels, and lymph spaces. The inner portion of the dermis consists of (3) a layer of very dense connective tissue (stratum compactum) in which the bundles of wavy connective tissue fibers run, in general, parallel to the surface of the skin. At intervals this layer is crossed by vertical strands which extend through the stratum spongiosum to the epidermis. These strands are made up of connective tissue fibers and also, in some cases, of muscle fibers, nerves, and blood vessels. Draw a portion of the section to show the structure as observed.

2. Cartilage. Examine, with the high power, a prepared section of hyaline cartilage. Note: (1) the transparent, homogeneous intercellular substance (matrix) which possesses (2) numerous spaces (lacunae). The latter contain (3) one or more nucleated cartilage cells. Note also, in various regions of the preparation, that the lacunae containing the cartilage cells show a tendency to group together. Draw a portion of the section to show the structure as observed.

AXIAL SKELETON

1. Examine the skull of a Dog or Cat. Note that it consists of the BRAIN CASE (CRANIUM), and the FACIAL PORTION which forms the framework of the face and jaws. Locate the bony SENSE CAPSULES which enclose and protect the nose, eyes, and ears. Observe the articulation of the lower jaw (MANDIBLE) at the posterior end of the skull with the posterior portion of the prominent ZYGOMATIC ARCH. Note the similarity and the relation of the teeth of both jaws and their adaptation for different purposes. Various openings (FORAMINA) are present in the skull bones, which serve as exits for the cranial nerves and blood vessels. The largest of these is the FORAMEN MAGNUM at the posterior end of the skull, through which the spinal cord passes into the cranium. On each side of the foramen magnum is a smooth, rounded, prominence (OCCIPITAL CONDYLE). The condyles fit into depressions on the first vertebra of the vertebral column, and thus articulate the skull with it.

2. Examine the surface of the skull and note that it is composed of a considerable number of bones which are jointed together by irregular SUTURES. Identify the following bones: (1) the OCCIPITALS, which form the posterior part of the skull around the foramen magnum; (2) the PARIETALS, which form a considerable portion of the dorsal and lateral walls of the cranium; (3) the TEMPORALS, in which the ears are located (consist chiefly of the dorsal SQUAMOSAL PORTIONS), lie ventral to the parietals, and from each of them there is (4) a curved projection (ZYGOMATIC PROCESS) which unites anteriorly with (5) the MALAR bone to form the ZYGOMATIC ARCH; (6) the FRONTALS which lie anterior to parietals and dorsal to the eye; (7) the median NASALS, which form the dorsal wall of the nose; (8) the MAXILLAE, and (9) the small PREMAXILLAE, which together form the upper jaw and a large portion of the roof of the mouth; (10) the PALATINES, which lie in the roof of the mouth posterior to the maxillary bones; (11) the median SPHENOIDS, posterior to the palatines, and (12) the MANDIBLE, or lower jaw.

3. Draw the skull from the left side, showing as many as possible of the parts mentioned above.

4. Examine a VERTEBRA from either the thoracic or lumbar region of the spinal column. Note: (1) the large, solid CENTRUM, with (2) the NEURAL ARCH lying dorsal and surrounding (3) the NEURAL CANAL; (4) the TRANSVERSE PROCESSES for the attachment of muscles, projecting laterally from each side; (5) the NEURAL SPINE, which projects dorsally from the neural arch, and (6) the ANTERIOR and POSTERIOR ARTICULAR PROCESSES. Draw the vertebra from either an end or a side.

APPENDICULAR SKELETON

1. With the structural plan of the vertebrate pentadactyl limb in mind, examine the mounted skeleton of a Dog or Cat and note the differences between the fore limbs and the hind limbs, together with their respective girdles.

2. Secure a detached fore limb and determine from the mounted skeleton whether it is a right limb or a left limb. Identify the following bones: (1) the shoulder blade (SCAPULA) with a median ridge; (2) the large HUMERUS; (3) the RADIUS, and (4) ULNA — the latter is the larger and forms the main articulation with the humerus; (5) the wrist (CARPUS), composed of seven CARPAL bones; (6) the hand, composed of five METACARPAL BONES and five DIGITS. Each of the digits consists of three bones (PHALANGES) with the exception of the first, corresponding to our thumb, which has only two. Make a reduced drawing of the entire fore limb.

3. Secure a detached hind limb and determine from the mounted skeleton whether it is a right limb or a left limb. Identify the following bones: (1) the PELVIS, which has a bony attachment to the vertebral column; (2) the large FEMUR; (3) TIBIA, and (4) FIBULA — the former is the larger and forms the main articulation with the femur; (5) the ankle (TARSUS), composed of seven TARSAL bones; the foot, composed of five METATARSAL bones, one of which is much reduced, and four digits — the first is lacking — each of which consists of three bones (PHALANGES). Make a reduced drawing of the entire hind limb.

4. For comparison, study the limbs of a Bird, Bat, Horse, and Man. Note, in all these types, the homologies of the principal bones, and their modifications, such as changes in form, consolidation, suppression, etc.

SPERMATOGENESIS

1. Examine, with the low and the high power, a prepared section of Mouse testis. Note that it consists of a great number of tubules (SEMINIFEROUS TUBULES) in the walls of which the sperm cells develop. The tubules are greatly convoluted, and consequently, in the preparation, they are sectioned in various planes. At one side of the testis a section of the EPIDIDYMIS may be seen. This is the conducting tube that carries the mature sperm from the testis. It corresponds, in general, to the vasa efferentia of the Frog testis (p. 236). Draw the entire testis in outline and fill in a portion with careful detail.

2. Select a seminiferous tubule which has been sectioned approximately transversely and study with the high power. Note the arrangement, size, and structure of the SPERMATOGONIA, SPERMATOCYTES, SPERMATIDS, and mature SPERM. Draw the entire tubule in outline and fill in a portion, showing, with careful detail, the germinal cells in various stages of maturation.

3. Examine the epididymis under high power. Note that the tubules are filled with mature sperm. Draw a tubule to show the structure as observed.

OÖGENESIS

1. Examine a fresh ovary of a Pig and note the numerous more or less transparent prominences (GRAAFIAN FOLLICLES) of various sizes in which the egg cells develop. The more mature follicles are larger and more transparent. Note also the hard, yellowish substance (CORPORA LUTEA) with which the cavity of a follicle is filled after the mature egg has been discharged. Make an enlarged drawing of the entire ovary to show the structure as observed.

2. Examine, with the low power, a prepared section of a Mouse ovary. Note the outer covering (GERMINAL EPITHELIUM) in which the eggs are first formed and from which they move into the body of the ovary, where they become surrounded by follicle cells, and thus form the Graafian follicles. The latter can be seen in various stages of development. In the immature follicles the large central egg is closely surrounded by several layers of the follicle cells. In the larger, more mature follicles, a liquid-filled cavity develops around the egg. In close contact to the egg are a few layers of the follicle cells which also support it at one point. Areas of the yellowish corpora lutea can also be seen in the preparation. The ground substance of the ovary consists of connective tissue with the numerous cells and blood vessels embedded in it. Draw the entire ovary in outline and fill in a portion to show the structure as observed.

3. Select the most mature follicle containing an egg with nucleus which your preparation shows. Study it carefully with the high power and draw the entire follicle in detail.

FERTILIZATION AND MITOSIS

1. Examine, with the low and the high power, a prepared transverse section of the uterus of Ascaris. Note the heavy uterine wall and the central cavity containing many thick-shelled eggs which are in various stages of mitosis. Draw the entire section of the uterus in outline and then fill in a sector to show the details.

2. Study the preparation with the high power. Identify eggs in the following stages of mitosis and make a drawing of each stage about two inches in diameter:

I. CONTACT of the male and female PRONUCLEI.

II. EARLY PROPHASE, with the chromatin in each pronucleus in the form of a long thread (SPIREME), and the centrosomes at opposite poles of the fusion nucleus (SYNKARYON).

III. LATE PROPHASE, with the chromatin in the form of definite CHROMOSOMES, the nuclear membranes broken down, and the SPINDLE well-developed.

IV. METAPHASE, with the chromosomes divided in the equatorial plate; or ANAPHASE, with the chromosomes moving along the spindle fibers toward the centrosomes.

V. TELOPHASE, with the spindle breaking down and the cytoplasm of the cell dividing to form two cells.

Label in each of the above stages where present: EGG SHELL, CYTOPLASM, CENTROSOMES, ASTERS, SPINDLE FIBERS, and CHROMATIN, or CHROMOSOMES.

DEVELOPMENT OF THE FROG (1)

1. Place an unsegmented Frog's egg in a watch glass containing water and examine it, both with the dissecting microscope and with the low power of the compound microscope. Note that the egg is enclosed in a transparent jelly, and that it consists of a dark-colored portion (ANIMAL POLE), which tends to lie uppermost in the water, and a lighter-colored portion (VEGETAL POLE). Make a drawing of the egg from the side, one inch in diameter, so as to show both poles and the jelly.

2. Examine, in the same way, the following segmentation stages of Frog's eggs: 2–4 cells, 8 cells, 20–30 cells, and many cells, or BLASTULA. Note in each stage the direction of the cleavage planes and the comparative size of the cells in the animal and vegetal poles. Make a drawing of each stage from the side, omitting the jelly.

3. Examine, as before, a Frog's egg in which the growth of the dark cells of the animal pole over the light cells of the vegetal pole has begun (GASTRULA). As this process of gastrulation continues, the circular area (BLASTOPORE) at the vegetal pole becomes smaller. Finally, when gastrulation is complete, the blastopore is very small, and only a tiny portion of the cells of the vegetal pole is visible externally, and this region is known as the YOLK PLUG. Draw the gastrula from the vegetal pole, showing the yolk plug.

DEVELOPMENT OF THE FROG (2)

4. Examine, in a watch glass of water as before, a later stage in the development of the Frog in which the body of the animal has begun to elongate in an anteroposterior direction. Note that the blastopore, which was circular, has now become a slit-like opening which marks the posterior end of the embryo. Note also the dorsal, longitudinal groove (NEURAL GROOVE) which indicates the position of the future central nervous system. Draw the embryo from the posterior end.

5. Examine, as before, still later developmental stages as follows: (1) an embryo in which the head and tail have just become differentiated; (2) an embryo with well-developed external gills; (3) a fully-formed, free-swimming tadpole, in which the external gills have become covered by the OPERCULUM, leaving only a small opening (SPIRACLE) on the left side of the animal in the gill region; (4) an embryo in an early stage of metamorphosis, showing a single, pair of small hind legs, and (5) an embryo in a late stage of metamorphosis, with both pairs of legs present and the tail in process of absorption. Draw each of these embryos from the left side and label in each stage, where developed: NOSE, EYE, MOUTH, SUCKER, GILLS, OPERCULUM, MUSCLE PLATES, BLASTOPORE, ANUS, and TAIL.

DEVELOPMENT OF THE CHICK (1)

1. Examine, with the dissecting microscope and with the low power of the compound microscope, a permanently mounted three-day Chick embryo. Note that the general shape resembles a 'reversed question-mark' with the head end turned toward the right. Anteriorly, the embryo is lying on its left side and, posteriorly, on its ventral surface. On each side of the embryo, note the VASCULAR AREA with the large vessels (VITELLINE ARTERIES and VITELLINE VEINS) which enter the embryo near the middle of the body.

2. Beginning at the posterior end of the body, identify the median spinal cord, and on each side of it the segmental, paired, muscle plates (MYOTOMES). Ascertain the number in your specimen. Find the AMNION which later completely encloses the embryo. At this stage it covers the anterior end of the embyro and ends somewhat posterior to the region where the vitelline vessels enter the body.

3. Study the anterior end of the embryo and locate: (1) the FORE-BRAIN, with the rudiments of the EYE and NOSE; (2) the large, rather spherical MID-BRAIN, and, to the left, (3) the smaller HIND-BRAIN, with a large, dorsal depression (FOURTH VENTRICLE). (4) The rudiment of the right EAR is situated near the posterior end of the hind-brain, and appears as a small, flask-shaped vesicle. (5) The twisted, S-shaped HEART lies outside the body wall in the space between the tip of the head and the curved portion of the trunk. It consists at this stage of (6) a large posterior VENTRICLE, into which (7) the AURICLE opens. A portion of the auricle can be seen to the left. Leading from the ventricle, anteriorly, is (8) the CONUS ARTERIOSUS. It soon divides to form a number of BRANCHIAL VESSELS which run dorsally between (9) the GILL SLITS to form a portion of the aortic arches.

4. Make a full page drawing of the entire embryo to show the structures as observed.

DEVELOPMENT OF THE CHICK (2)

1. Place an egg, which has been incubated three days, in a finger-bowl of warm (about 38° C) normal salt solution, with the blunt end pointing to your right. Hold the submerged egg firmly with one hand, and, with the other, carefully insert the point of the scissors in the center of the blunt end. Be *very careful* to use only the extreme tips of the scissors in cutting the shell. While holding the egg in the *same position* continue the cut entirely around the egg a little *below* the equator, and then lift off the upper portion of the shell, leaving the rest of the egg, including the lower portion of the shell, with the embryo, immersed in the salt solution.

2. Examine, with the dissecting microscope, the translucent embryo lying on the yolk in the center of the VASCULAR AREA, noting how it is placed with reference to the long axis of the egg. Note the beating HEART, the VITELLINE ARTERIES and VEINS which pass out to the side from the middle of the embryo, and the anterior VITELLINE VEIN which runs under the anterior portion of the embryo. Determine the PULSE RATE. Make a drawing of the entire specimen, with the embryo *in situ*, to show the structures observed.

3. Carefully make a circular cut, with small scissors, through the egg membrane, just outside the limit of the vascular area. With fine forceps take hold of an edge of the detached area and very gently separate it, with the attached embryo, from the underlying yolk. Hold the detached portion with the forceps, below the surface of the liquid, and with the other hand immerse a watch glass in the liquid. Carefully float the embryo into the watch glass, keeping it at all times below the surface of the liquid. Gently raise the watch glass and remove it, with the embryo floating in it, entirely from the finger-bowl, taking great care not to lose the embryo. With a pipet draw off a considerable portion of the fluid around the embryo, and replace it with a fresh supply of warm salt solution.

4. Examine the embryo with the dissecting microscope, and identify the structures which you previously noted in the permanent preparation of the three-day chick embryo. Under the low power of the compound microscope observe the movement of the red blood corpuscles in the blood vessels.

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